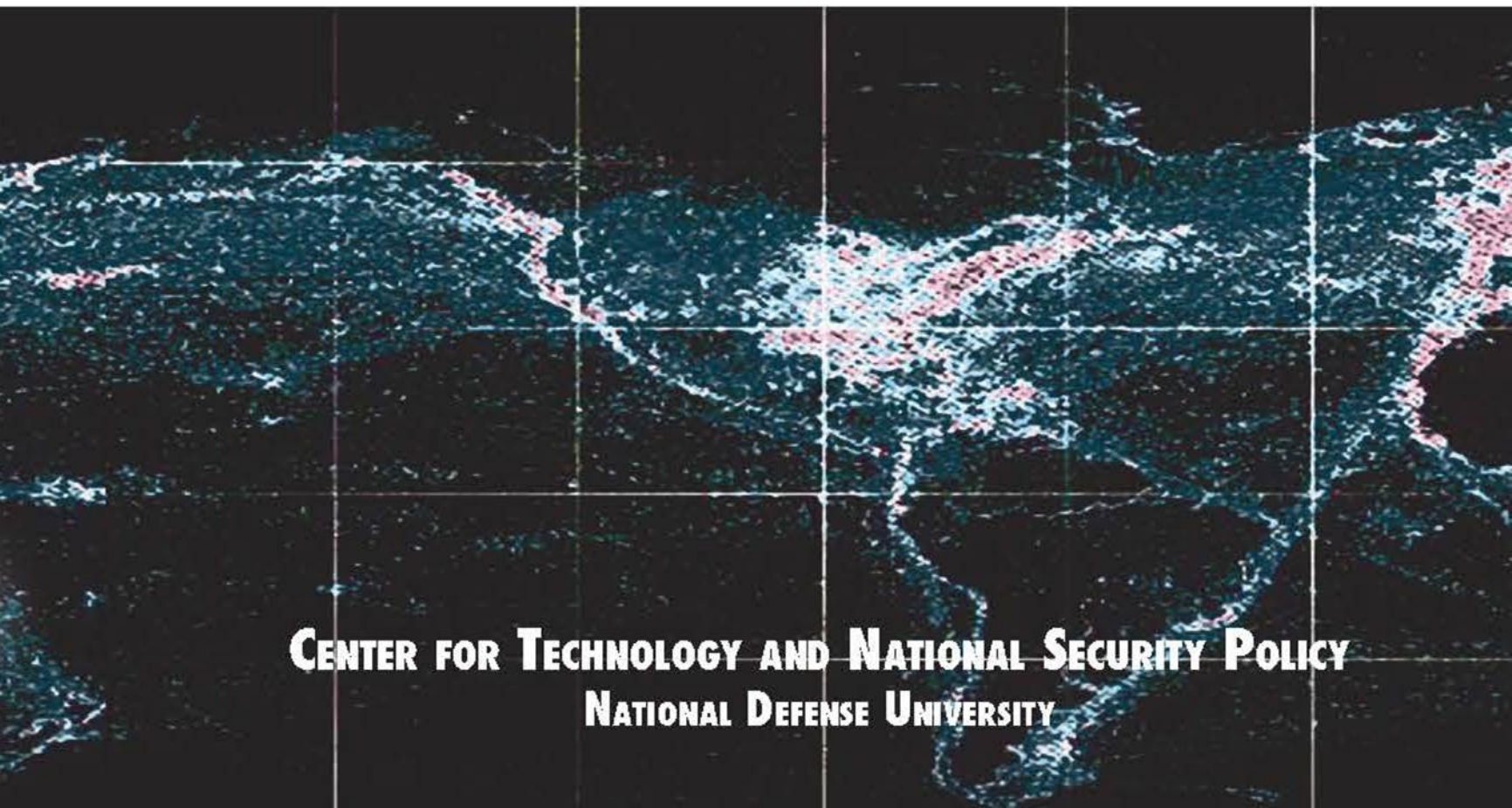
Defense & Technology Paper 102

"Chance favors only the prepared mind"
The Proper Role for U.S. Department of Defense Science and Engineering Workforce

Timothy Coffey



Center for Technology and National Security Policy
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Washington, DC

August 2013

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Executive Summary

The U.S. Department of Defense (DOD) is entering a period of great complexity and high uncertainty. In such times it is prudent to return to fundamental principles. One key principle that should be kept in mind is that warfare is not a matter to be left to the free market. In the cases of national defense and warfare, societies have traditionally declared a government monopoly. In the United States, that monopoly is currently vested in the DOD. In this capacity, the DOD is responsible, subject to policy guidance from elected and appointed officials, for charting the future direction for the nation regarding national defense. While the DOD will receive both solicited and unsolicited advice as it undertakes this task, it bears the full responsibility for the task. The quality of the undertaking will only be as good as the people employed by DOD. The outcome of the required calculus for charting the future direction will depend on many factors, among which are:

- DOD's ability to recognize significant developments (military, political, economic, scientific and technical) before they become obvious.
- Recognition that DOD's ability to determine the long-term directions is constrained by the fact that long range predictions are greatly hampered in the presence of complexity and uncertainty. The greater the uncertainty and the longer the prediction time horizon the more tenuous will be the predictions.
- The DOD's ability to separate the best interests of the government from the interests of the multitude of parties vying for influence and for federal resources.
- It is generally agreed that developments in science and technology will play an increasingly important role in military affairs. It is also understood that there are large ex-ante uncertainties regarding the usage of new scientific and technological capabilities. These two realities have significant implications regarding how the DOD conducts its research and development (R&D) programs and its major acquisition programs. They suggest that:
- The DOD science and technology (S&T) program should be viewed as a vehicle by which the large ex-ante uncertainties associated with new science and technologies are reduced and should be vigorously prosecuted accordingly.
- Major acquisition programs should be very conservative regarding the introduction of new technologies prior to the uncertainties associated with them being substantially reduced.
- The major acquisition programs and the S&T programs should be managed as separate tracks. Items in the major acquisition track should have a high expectation for success while what is done in the S&T track should have a high potential impact but a low expectation for transition. A vehicle for connecting the two tracks, when appropriate, needs to be in place.

The latter conclusion may seem counter intuitive to the success oriented DOD. However, the conclusion is reflective of reality. If a large portion of the S&T program transitions to major acquisition programs then, either the S&T program is too conservative and is not protecting DOD's long term interests or the unresolved uncertainties associated with new technologies will be resolved in the major acquisition programs at great, yet avoidable expense.

The DOD in-house science and engineering workforce plays a key role in responding to the conclusions stated above. This workforce currently numbers about 130,000. These scientists and engineers (S&Es) work in a variety of settings. About one third work in the DOD laboratories. Of the remaining two thirds, the majority work at the Major Range and Test Facilities, the Operational Test Agencies (OTA) and in the Acquisition Workforce. Collectively these individuals form the government cadre of skilled scientists and engineers who strive to ensure that the DOD acquires, tests, and maintains advanced military systems and develops the advanced military technologies needed for future use. Many of today's military capabilities originated in the DOD in-house activities and were transitioned to production through collaborations and sometimes competition among DOD in-house activities and out-of-house activities. In order for this to continue the DOD must conduct and manage its research, development, test and evaluation (RDT&E) programs such the DOD S&E workforce gains the hands-on experience that will attract and retain the talent necessary to fulfill the public trust in the conduct of the DOD business and in charting the future direction. The DOD mission itself provides the means to accomplish this objective. However, doing so requires a deliberate strategy regarding the balance of what is done in-house by DOD S&Es and what is done out-of-house by contractors of various sorts. Among the objectives of this strategy should be to:

- Provide the hands on experience needed to maintain in-house competence in science and engineering.
- Help sort out the promising technologies and technical directions from the less promising
- Provide for competent internal government advocacy regarding the directions in which DOD should move.
- Provide the necessary competent "third party" through which the DOD buyers can determine a fair and equitable price in the bargaining process associated with the bi-lateral monopoly that exists between the DOD and the defense industry.

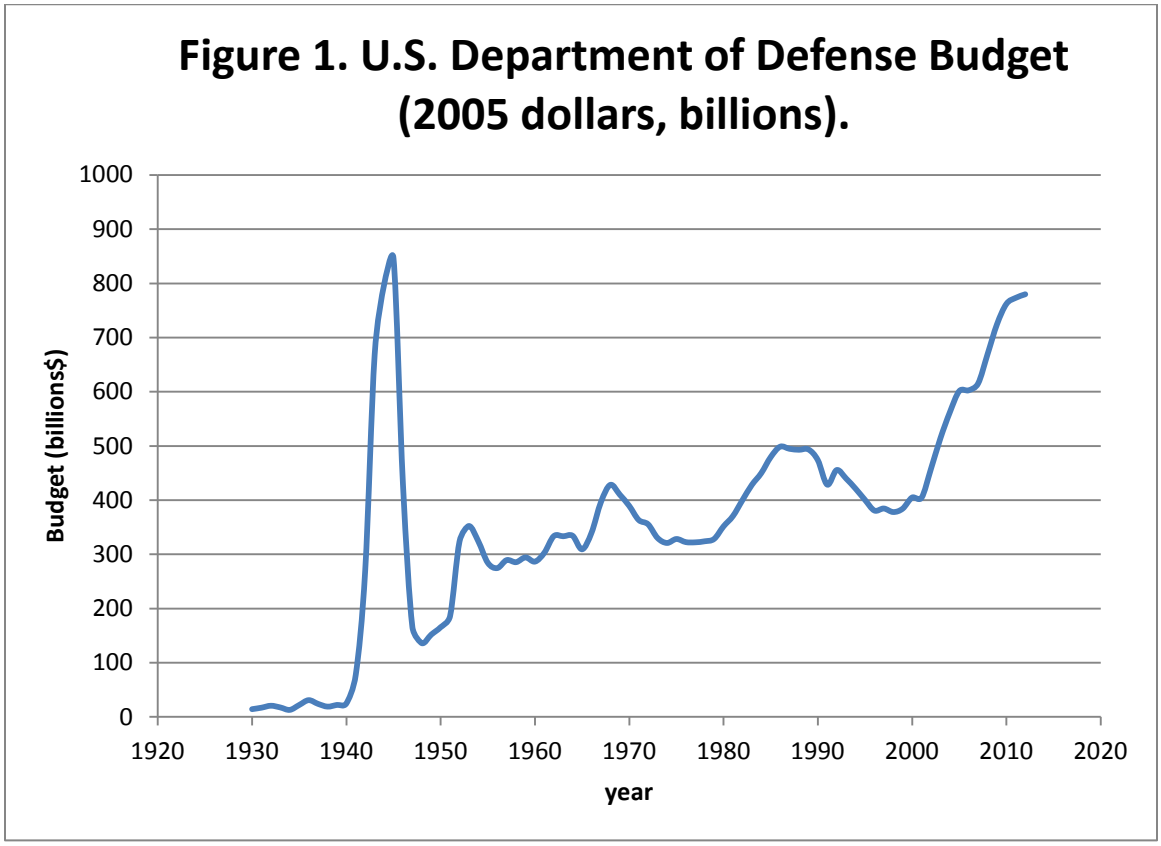
For advanced weapons systems, platforms and technology, the role for in-house S&Es suggested above requires a high degree of scientific and technical knowledge and authority as well as an understanding of what DOD needs and how DOD, as an institution, operates. If the government is to play this role it must be able to hire and retain the scientific and engineering talent needed to accomplish this function. A metrics-based comparison of three government R&D institutions staffed with federal S&Es with six not-for-profit R&D institutions staffed with contractor employees demonstrates the federal S&Es are of at least as high stature and recognition as the not-for-profit institutions. This demonstrates that one can run high quality R&D establishments inside the government with federal S&Es and outside of the government with non-federal S&Es. Therefore, DOD can certainly hire the necessary S&E talent if it takes the appropriate measures. Its strategy for doing so must consider providing hands-on experience to the government S&Es. This involves the S&Es: investigating rapidly changing fields of science and engineering, bringing the problems of the armed forces before the broad scientific and technical communities in terms of technical discourse, providing objective advice regarding contract research and development programs, maintaining understanding of and sensitivity to the government's interests, helping manage weapons system development and test programs, assisting the military user to understand what is technically feasible and assisting in the technical education for

military officers. The strategy must also include developing strong ties with colleges and universities that involve joint research and work assignments for students and faculty at DOD R&D facilities. This will go a long way towards creating the lasting bonds between DOD and the larger scientific and technical community that are needed to sustain the DOD S&E workforce in the long term.

While this paper focuses on the DOD in-house S&E workforce, a brief comment is made regarding initiatives underway to modify the reporting relationships and missions of the nation's nuclear weapons laboratories. It is suggested that considerable caution should be exercised before taking actions that could cause dilution of the nuclear weapons laboratories expertise and focus on nuclear weapons and caution should be exercised as well before taking actions that could cause dilution of the capability of the existing DOD RDT&E infrastructure and the expertise of its associated S&E workforce. Any rationalization of the Defense RDT&E program should take this larger view into account. This is especially true at this juncture where the coming years are likely to be difficult ones regarding maintaining the national security enterprise, as DOD anticipates a decade of declining funding. This is a topic which requires analysis of possible unintended consequences on the current and effective nuclear and non-nuclear components of the national defense RDT&E programs and further study is in order.

I. Introduction

The U.S. Department of Defense (DOD) is, once again, in a period of transition. In some sense, there is nothing new about this. It is well recognized that spending by DOD is episodic. This is evident in Figure 1 which displays the DOD budget from 1929 through 2012.



Since WWII, DOD expenditures have oscillated about a slowly increasing mean value. Each of the upswings is associated with a particular development: The first upswing is World War II, the second is the Korean War, the third is the Vietnam War, the fourth is the Reagan buildup, and the most recent represents the Afghanistan and Iraq wars. Each upswing has been followed by a nearly equal downswing. It is, therefore, reasonable to expect that the last upswing will be followed by a significant downswing. If history is an indication, the current downswing will total about $400 billion dollars and the bottom will be reached around 2020 at which time some as yet undetermined event will begin another upswing. Of course, past performance is no guarantee of future performance and the next downswing will result from the management of a number of factors. Among these are:

- End of Iraq war and phase out of Afghanistan war.
- Concern with the national debt.
- Growing costs of social safety nets (Medicare, Medicaid, Social Security).
- The proper role for DOD in combating terrorism.

- Absence of a military peer competitor.
- Potential emergence of a military peer competitor.
- Growing cost of the all-volunteer force.
- Growth in use of private security contractors.
- The outsourcing of an increasing number of defense services.
- The increasing costs of defense systems and platforms.
- Concerns regarding the quality of decisions made by the defense acquisition system.
- The role/fate of the US defense industrial base.
- The role/fate of the defense government workforce.
- The globalization of science and technology.
- Control of the emerging global arms industry.

The calculus facing DOD is further complicated by the fact that there are vocal advocates and detractors associated with each item on the list. One should nevertheless take some comfort from the fact that DOD has successfully managed the required adjustment several times since World War II even though today's situation is qualitatively and quantitatively different from the past. For example, some of the items, such as private security contractors, outsourcing of defense services, role of DOD in combating terrorism, globalization of science and technology, would likely not have been significant factors in the previous draw downs. Other items like the global arms industry, increasing cost of defense systems, defense industrial base, DOD federal workforce, while not new, may have reached a tipping point where the usual calculus may not be appropriate. This has been discussed recently by Gansler.[1] In addition, some of the items like the national debt, entitlement programs will have a significant impact on DOD but are not within the control of DOD and are likely to show up as boundary conditions on DOD budget.

The outcome of the current transition calculus will depend on many factors key among which are DOD's ability to separate the best interests of the government from the interests of the multitude of parties vying for influence and for federal resources, and to determine the long-term directions for DOD. It is the U.S. Government's (USG) job to make this determination as part of the public trust. The government gets no certificate of non-responsibility by outsourcing this function. The quality of the determination will be only as good as the people employed by the government to assist in making the determination. The public deserves and should insist that the government is staffed with individuals of the highest stature and competence needed to ensure that the best interests of the government are being pursued rather than the interests of those vying for influence and for federal resources. This statement is intended to apply to all fields upon which the government depends and where it has special responsibilities that should not be left to the private sector. However, this paper will focus on the area of research and development (R&D) and especially of DOD R&D.

The following sections will attempt to provide a simple context for DOD in order to assist in understanding its scale and complexity. The importance of the competence the federal workforce will be emphasized. The implications of understanding the role of complexity and uncertainty regarding DOD's future directions will be discussed. DOD as an employer of scientists and

[1] Jacques S. Gansler, *Democracy's Arsenal: Creating a Twenty-First-Century Defense Industry* (Cambridge, MA: The MIT Press, 2011).

engineers will be reviewed. The role that these scientists and engineers should play in the bi-lateral monopoly that exists between DOD and the defense industry will be discussed as will the prospects for DOD being able to hire the scientists and engineers necessary to fulfill this role. A brief comment will be made regarding potential implications of initiatives underway to modify the reporting relationships and missions of the U.S. nuclear weapons laboratories.

II. A Simple Context for DOD

When discussing a complex subject it is often helpful to place it in a simpler but still valid context. This is useful because it places bounds on the subject under consideration. In this regard we note that Paul Samuelson, the nation's first Nobel Laureate in economics, made the observation that

More than this, government provides certain services without which community life would be unthinkable, and which by their nature cannot appropriately be left to private enterprise. Governments came into existence once people realized, "Everybody's business is nobody's business." Obvious examples are the maintenance of national defense, of international law and order, and the administration of justice.[2]

In consonance with this view, the U.S. Constitution vests all military matters in the U. S. Congress and the President. Up to this point in our history, the federal government has exercised a buyer's monopoly regarding national defense and warfare. The current embodiment of that monopoly is DOD. We will take the viewpoint that this monopoly is appropriate, necessary, and should continue. This has obvious implications regarding matters such as DOD business practices, employment objectives, and private sector involvement.

By any measure, DOD is a massive undertaking. If one were to view DOD as a company, it would be the world's largest company and the world's largest employer.[3] If one viewed DOD as a country and compared DOD expenditures with various country GDPs, DOD would rank as the world's 21st largest country. The dynamic range of DOD purchases is vast, ranging from routine commodities and services to the worlds most sophisticated weapon systems and platforms to pioneering scientific and technical undertakings that will determine U.S. war fighting capabilities 30 years hence. While the company analogy provides some sense of scale, it must be understood that DOD is not a company: It is a government entity that exists to fulfill a public trust. It must be viewed, managed, and judged in this context.

In pursuit of this trust and as a result of its scale, complexity, and importance, DOD employs people in nearly every career field. The current active duty military component of this workforce involves about 1.5 million people. The civilian component involves about 718,000 people.[4] These numbers do not include supporting contractor employees. The purpose of this workforce is to ensure that the armed forces are able to play their part in maintaining the peace and defending the United States and its interests and are equipped and trained to respond to the requirements of the National Command Authority. While much of what is required of DOD is straightforward, some of what is required is quite sophisticated and often lacks precedent. This aspect of DOD employment contributes to DOD's historic ability (and need) to attract and retain some of the nation's finest talent in a wide variety of fields, among which are: aviation, business, combat operations, communications, construction, education, engineering, environment, finance, health care, human resources, information technology, intelligence, international relations , land vehicles, law, logistics, naval and maritime operations, science, security, social science, training, transportation. Historically, DOD has contributed to the advancement of many of these fields to

[2] Paul A. Samuelson, *Economics: An Introductory Analysis*, 4th ed. (NY: McGraw-Hill, 1958).
[3] In 2012, the U.S. Department of Defense had a total of 3.2 million employees. Ruth Alexander, "Which is the World's Biggest Employer?" *BBC News*, March 19, 2012, available at <www.bbc.co.uk/news/magazine-17429786>.
[4] See "About the Department of Defense," *U.S. Department of Defense*, available at <www.defense.gov/about/>.

the general benefit of the nation. DOD has been able to attract the necessary talent because of the importance to the nation of DOD mission, because the challenges that are presented are, at times, fascinating and unique and because of the satisfaction of seeing a product result from one's efforts. Maintaining this historic internal competence will be essential if DOD is to meet its obligations in an increasingly complex world.

III. "Competence" vice "Inherently Governmental"

The purpose of the above discussion is to remind ourselves that DOD is more than a buyer of goods and services. DOD is responsible for charting the future direction for the nation regarding national defense. That undertaking involves decision-making in an environment of high uncertainty. It also requires the ability to recognize significant developments in the military, political, economic, scientific and technical realms before they become obvious. In order to accomplish these tasks, DOD must be properly staffed and must undertake the appropriate programs. The matters of how DOD should be staffed and the proper mix of programs that should be conducted by DOD itself and those that should be conducted by organizations outside of government has been the subject of debates that go back to the beginning of the republic. Some insight into the different perspectives of this debate can be gained from Hazel[3] and from Gansler.[5] The debate has never been resolved and probably never will. It waxes and wanes in accordance with the episodic nature of DOD spending. When the budgets are growing and a national urgency is apparent, there is enough work to keep both sides of the debate productively occupied with responding to the emergency. When the spending decline inevitably sets in, the debate ignites once again. It is often cast in the context of "inherently governmental functions." This metric, however, is difficult to define and, accordingly, is subject to different interpretations.[6] From the author's perspective, the debate regarding the proper role of government is legitimate and should continue. However, the debate over the semantic definition of "inherently governmental" is a waste of time. The proper issue to consider is that of assuring that DOD has the experienced staff needed to meet its obligation to provide for the national defense. This involves far more than administering the movement of money to the private sector. The profound questions confronting DOD are: what it should do, where it should go, and what it must do to get there. Even more profound is the reality that there are many possible outcomes due to the uncertainties involved. Furthermore, DOD can deliberately or inadvertently change the outcomes based upon its own actions. It is a requirement of the public trust to ensure that DOD has the organic competence needed to sort its way through this complexity and uncertainty. This matter of competence is the correct issue upon which to focus.

[5] J. Eric Hazel, *From Reform to Reduction: Reports on the Management of Navy and Department of Defense Laboratories in the Post-Cold War Era* (Washington, DC: National Defense University and the Naval Historical Center, 2008); Gansler, *Democracy's Arsenal*.

[6] For a discussion of various definitions of inherently governmental functions see John. R. Luckey, Valerie Baily Grasso and Kate M. Manuel, *Inherently Governmental Functions and Department of Defense Operations: Background, Issues, and Options for* Congress, R4064 (Washington, DC: Congressional Research Service, July 22, 2009).

IV. Implications of complexity and uncertainty for DOD R&D

A DOD organization and program that reflects an understanding of how things actually happen rather than embracing some ideology or revisionist history is essential to DOD in meeting its obligations. Nowhere is this truer than in DOD R&D program. The subset of R&D that involves basic research and exploratory development is generally referred to as science and technology (S&T). As S&T has come to play an increasingly significant role in human endeavors it has become accepted that the ascendance of today's technology is related to past investments in S&T.[7] Technology plays an important role in creating jobs, wealth, improving health, and establishing and maintaining military superiority. It is clearly a success story. However, the success story is not the whole story.

The focus on success obscures the vital role that failure has played in enabling success. For example, it is a fact that about 60 percent of high technology start-up companies will fail within four years of initiation.[8] It is a fact that the majority of scientific publications submitted to high impact journals are rejected. For example, the high impact journal, *Nature* has an acceptance rate of less than 10 percent.[9] It is projected that, of the 1.5 million patents in force in the United States, only about 3,000 are commercially viable.[10] One can reasonably conclude from this data that high-tech entrepreneurial activity and advanced science and technology undertakings are, a priori, unlikely to succeed in a practical sense. Those efforts that do succeed in significant ways are often analyzed in order to ascertain why they succeeded so as to provide guidance to future endeavors. While some wisdom has emerged from these ex post facto analyses, it seems unlikely that the success rate can be markedly improved. In this regard, it is well established that many of the great scientific discoveries were serendipitous in that they were not and could not have been planned. [11] It is also becoming increasingly clear that great changes and advances in technology are as unpredictable as great scientific shifts. This has to do with problems associated with making predictions when the underlying base of knowledge is uncertain and when the environment is complex. In this situation, there are many possible outcomes for any undertaking. The greater the uncertainty and the longer the prediction time horizon the more tenuous will be the predictions. The high failure rates cited above are driven mostly by the natural process of identifying and resolving the underlying uncertainties. This situation will not change. However, DOD should keep in mind Pasteur's insight that, "In the fields of observation chance favors only the prepared mind."[12]

DOD, as a success oriented organization that is obsessed with planning, is vulnerable to asserting that a particular outcome will be achieved and declaring that dissenting views are to be avoided. However, such attempts to artificially constrain the selection process are likely to be counter-

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[7] *Capitalizing on Investments in Science and Technology* (Washington, DC: National Academy Press, 1994), available at <www.nap.edu/openbook.php?record_id=6442&page=R1>.

[8] Amy E. Knaup, "Survival and longevity in the business employment dynamics data," *Monthly Labor Review* 128, no. 5 (May 2005), 50-56.

[9] See "Getting Published in *Nature*: The Editorial Process," *Nature*, Homepage, available at <www.nature.com/nature/authors/get_published/>.

[10] See interview with Richard Maulsby, U.S. Patent and Trading Office, 2005. "Avoiding the Inventor's Lament, *Bloomberg Business Week*, November 9, 2005, available at <www.businessweek.com/stories/2005-11-09/avoiding-the-inventors-lament>.

[11] Royston M. Roberts, *Serendipity: Accidental Discoveries in Science* (NY: Wiley & Sons, July 1989).

[12] From L. Pasteur, Lecture, University of Lille, December 7, 1854, in René Vallery-Radot, "The Life of Pasteur" R. L. Devonshire, trans. (New York: Garden City Publishing Co., 1900), 79.

productive. Nathan Rosenberg, highly regarded for his studies on the nature of technological progress, summarized the situation as follows:

Bad bets are, of course, common, indeed so common that it is tempting to conclude that the manner in which competing firms pursue innovation is a very wasteful process. Such a characterization would be appropriate were it not for a single point: uncertainty. In fact, a considerable virtue of the marketplace is that, in the face of huge ex ante uncertainties concerning the uses of new technological capabilities, it encourages exploration along a wide variety of alternative paths. This is especially desirable in the early stages, when uncertainties are particularly high and when individuals with differences of opinion (often based upon differences in access to information) need to be encouraged to pursue their own hunches or intuitions. Indeed, it is important that this point be stated more affirmatively: The achievement of technological progress, in the face of numerous uncertainties, *requires* such ex ante differences of opinion.[13]

The realities discussed above have significant implications regarding how DOD conducts its R&D programs and its major acquisition programs. It suggests that the DOD S&T program should be viewed as a vehicle by which the large ex ante uncertainties associated with new science and technologies are reduced. In accordance with the above discussion, while the S&T programs should strive to succeed, one should expect high failure rates in this undertaking due to the uncertainties inherent in advanced, leading edge S&T efforts. In this arena, failure should not be viewed in a negative sense. It should be viewed as part of the natural process of identifying those few things that will succeed. Most of what is done in the S&T program will not transition to major acquisition programs. This is as it should be. While most will not transition, some should. A purpose of the S&T program is to contribute to finding those outcomes that are, ex post facto, viewed as successes. DOD Scientist and Engineer (S&E) participation in the S&T program is essential to finding these successes and such participation helps develop the hands on experience and judgment required for a competent DOD S&E workforce.

The high failure rates expected for new technologies suggest that major acquisition programs should be very conservative regarding the introduction of new technologies prior to the uncertainties associated with them being substantially reduced. The major acquisition programs and the S&T programs should be managed as separate tracks. Items in the major acquisition track should have a high expectation for success while what is done in the S&T track should have a high potential impact but a low expectation for transition. This latter assertion may seem counter intuitive to the success-oriented DOD. However, the assertion is reflective of reality. If a large portion of the S&T program transitions to major acquisition programs, then either the S&T program is too conservative and is not protecting DOD's long-term interests or the unresolved uncertainties regarding new technologies will need to be resolved in the major acquisition programs at great expense.

While the major acquisition programs and the S&T programs should be managed as separate tracks, there does need to be a process that provides a transition path for those few technologies that are determined to be appropriate for transition. This process should be resourced sufficiently to develop prototypes and conduct demonstrations at scales that are necessary to provide confidence in the value of a transition. The management of this process must be carefully

[13] Nathan Rosenberg, *Uncertainty and Technological Change*, presentation to the National Academy of Sciences, July 1994, available at <www.bostonfed.org/economic/conf/conf40/conf40d.pdf>.

designed and placed so as to maximize objectivity and minimize conflicts of interest. If done properly, this can contribute significantly to developing the hands-on experience and competence of the DOD S&E workforce, to resolving the uncertainties regarding the technical directions in which DOD should move, and to controlling the cost growth on future DOD weapon systems.

V. DOD as an Employer of Scientists and Engineers

The topic of principal interest here is the defense federal S&E workforce and its relationship to the defense industrial base, the cost of weapon systems, the global arms industry, and the globalization of S&T. We will focus on this but would assert that, in spirit, many of the underlying considerations are applicable to the larger professional defense federal workforce.

In a previous paper, it was shown that the number of people involved in S&E-type work employed by DOD shows episodic time dependence similar to that in Figure 1.[14] In other words, the number of scientists and engineers (S&Es) follows the same trajectory as that of the DOD budget. At the present time DOD employs about 130,000 S&Es.[15] This number, while tracking the defense program, represents about 2 percent of the national S&E workforce.[16] In 1960 the comparable number represented about 7 percent of the national S&E workforce.[17] The relative decline is expected to continue and its potential impact has been previously discussed by Coffey and Ramberg.[18] DOD S&Es work in a variety of settings with about one-third working in DOD laboratories.[19] The majority of the remaining two thirds work at the Major Range and Test Facilities (MRTF), the Operational Test Agencies (OTA) and in the Acquisition Workforce.[20] Collectively these individuals form the USG's cadre of skilled scientists and engineers who strive to ensure that DOD can acquire, test, and maintain advanced military systems, and can develop the advanced military technologies needed for future use. In order for this to continue DOD must conduct and manage its Research, Development, Test and Evaluation (RDT&E) programs such that the DOD S&E workforce gains the hands-on experience that will attract and retain the talent necessary to fulfill the public trust. DOD mission itself provides the means to accomplish this objective. However, doing so requires a deliberate strategy regarding the balance of what is done in-house by DOD S&Es and what is done out-of-house by contractors of various sorts. That DOD has been able to do this in the past is evidenced by the fact that many of today's military capabilities originated from in-house activities and were transitioned to production through collaborations and sometimes competition among DOD in-house activities and out-of-house activities.[21] If done properly, all parties benefit. A properly balanced workforce helps sort out the promising technologies and technical directions from the less promising. It provides the hands on experience needed to maintain in-house competence in science and engineering, for

[14] Timothy Coffey, *Building the S&E Workforce for 2040: Challenges Facing the Department of Defense*, Defense and Technology Paper 49 (Washington, DC: Center for Technology and National Security Policy, July 2008).
[15] Jocelyn M. Seng and Pamela Ebert Flatau, *Assessment of DOD Laboratory Civilian Science and Engineering Workforce*, P-000914 (Washington, DC: The Institute for Defense Analyses, July 2009).
[16] Total U.S. S&E workforce of 5.4 million. "Chapter Three: Science and Engineering Work Force," *National Science Foundation*, Homepage, 2012, available at <www.nsf.gov/statistics/seind12/c3/c3h.htm>.
[17] Coffey, *Building the S&E Workforce for 2040*.
[18] Tim Coffey and Steve Ramberg, *Globalization of S&T: Key Challenges Facing DOD*, Defense and Technology Paper 91 (Washington, DC: Center for Technology and National Security Policy, February 2012).
[19] Jocelyn M. Seng and Pamela Ebert Flatau, *Assessment of DOD Laboratory Civilian Science and Engineering Workforce*, P-000914 (Washington, DC: The Institute for Defense Analyses, July 2009).
[20] Ibid.
[21] See John Lyons, Richard Chait, and Duncan Long, *Critical Technology Events in the Development of Selected Army Weapon Systems*, Defense and Technology Paper 35 (Washington, DC: Center for Technology and National Security Policy, September 2006); Ivan Amato, *Pushing the Horizon: Seventy-five Years of High Stakes Science and Technology at the Naval Research Laborator*y (Washington, DC: U.S. Government Printing Office, 1998); Norman Friedman, *Seapower and Space: From the Dawn of the Missile Age to Net-Centric Warfare* (Annapolis, ME: Naval Institute Press, 2000).

competent internal government advocacy regarding the directions in which DOD should move in order to be prepared for the uncertain future, and for S&Es within DOD to deal with the private sector as peers. Also, it provides an instrumentality by which DOD buyers can determine a fair and equitable price in the bi-lateral monopoly that exists between DOD and the defense industrial base.

VI. The Bi-Lateral monopoly

Within the United States' system of government, DOD has a monopoly regarding the use of force against foreign adversaries. This monopoly obliges DOD to maintain, train, and equip the forces necessary to fight and win the nations wars. As such, DOD is a buyer of goods and services from the private for-profit and not-for-profit sectors. In this capacity DOD has, among others, the following responsibilities:

- Understand the government's interests
- Understand the time requirements associated with the government's interests
- Decide what should be purchased.
- Negotiate a fair and reasonable price
- Verify that what is delivered meets specifications

DOD must possess the internal competence to accomplish these responsibilities. The nature of the needed competence depends upon what DOD is buying. For example, much of what DOD purchases can be classed as routine items. Such items might include: food, aviation fuel, clothing, paper goods, among many others. For such items there exists a readily identifiable and extensive commercial marketplace that can assist the government in meeting its buying responsibilities. One can assert that a free market applies. However, in the cases of advanced weapon systems, platforms, and DOD advanced technology, an extensive commercial market place does not and cannot exist. Here DOD is confronted with, at best, a few specialized suppliers, which are collectively known as the defense industrial base, who produce similar products and who are largely dependent on DOD funding for their existence. This situation is described by economists as an oligopoly. In this situation, the few suppliers tend, either tactically or collusively, to gravitate to a common price. In effect they constitute a de facto monopoly. Since DOD has a buyer's monopoly on the purchase of advanced weapon systems, we have what is referred to as a bi-lateral monopoly existing between DOD and the defense industrial base. The concepts of monopoly, oligopoly, and bi-lateral monopoly are among the most elementary in the field of economics and have been extensively studied in the economics literature.[22] The key conclusion from the literature is that, in a bilateral monopoly, there is no price that simultaneously maximizes the desire of the monopoly buyer to minimize cost and the monopoly seller to maximize profit. The price is, therefore, determined by bargaining or by collusion. While collusion will lead to closure and perhaps even a reasonable price, it would not be viewed as being in the best interest of the government. This leaves bargaining as the only viable route. Convergence via this route will depend on the relative bargaining power of the two sides. A study of this problem in DOD context was reported by Van Veen for the case of purchases from sole source providers. A primary conclusion of that research is that "attaining a bargaining agreement that reflects a fair and reasonable price under bilateral monopoly conditions is not

[22] See Lyons, Chait, and Long, *Critical Technology Events in the Development of Selected Army Weapon Systems*; Amato, *Pushing the Horizon*; Norman Friedman, *Seapower and Space: From the Dawn of the Missile Age to Net-Centric Warfare* (Annapolis, ME: Naval Institute Press, 2000).

possible unless the Government possesses adequate information to accurately assess the fairness and reasonableness of the offered price."[23]

In the case of buying advanced weapon systems or advanced science and technology, the information needed to authoritatively assess the fair and reasonable price requires highly specialized knowledge. For this, DOD buyers must turn to organizations that are believed to have minimal or no conflict of interest in the matter at hand but are qualified to comment on the purchase. We will refer to these organizations as *third parties*. In principle, these third parties could reside in the government, in not-for-profit organizations, or in for-profit organizations that are assessed to have no interest in the outcome of the bargaining process. The matter of the third party in the bargaining process is important and one that has not received adequate attention. The main issues here relate to technical competence, objectivity, conflicts of interest, an understanding of how DOD system works, and ease of access.

It is likely that any organization that is technically competent to provide the required advice in these highly specialized fields will, to some degree, have objectivity problems, or/and de facto conflict of interest problems. This is true whether the party is government, not-for-profit or for-profit. The organizations, if knowledgeable, will likely have formed opinions of the sellers, may have decided independently regarding the viability of the proposal, and may even wish to develop and pursue concepts alternative to those proposed. It is a simple reality that the various third party organizations are striving to survive and are explicitly or implicitly "selling" to DOD or its contractors. These potential difficulties become problems only if they are not acknowledged and properly dealt with.

In the matters of objectivity and de facto conflict of interest, the issue becomes one of degree and of control. DOD, as the monopolistic buyer, is responsible for the decisions regarding what it should buy and what is a fair and reasonable price to pay. In this situation, to the extent practicable, it would be best if the third party advisors were provided by government organizations. In this case, the third party is the government and the monopoly remains intact. While this does not totally eliminate problems associated with objectivity and de facto conflict of interest, it provides the greatest degree of control over them. Furthermore, the government can access government employees directly without having to establish other transaction vehicles such as contracts. The use of government organizations in the third party role has the additional benefit of creating the expectation on the part of DOD that the various government third party organizations will maintain the competence necessary to meet this obligation.

[23] D. Van Veen, "Bargaining Tactics and Strategy in a Government/Contractor Bilateral Monopoly," *Thesis* (Monterey, CA: Naval Postgraduate School, March 1998), v, available at <www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA345044>.

VII. Can DOD Maintain the Necessary In-House S&E Competence?

As mentioned earlier, the third party role associated with advanced weapons systems, platforms and technology involves possession of a high degree of scientific and technical knowledge, and authority, as well as an understanding of what DOD needs and how DOD, as an institution, operates. If the government is to play the third party role it must be able to hire and retain the scientific and technical talent needed to accomplish this function. The question becomes: can the government hire the needed talent? The answer given to this question usually depends upon who is asked. In order to understand this, it is helpful to articulate more specifically what is expected of the in-house S&E workforce. Harold Brown, then the Director of Defense Research and Engineering, articulated, in 1961, four roles that he expected a DOD laboratory to fulfill.

First, the Defense Laboratories should form a spearhead which must provide the Armed Forces with at least two essential services: 1) They must continuously investigate rapidly changing fields of science and engineering to find materials, techniques, processes, and ideas which may prove to have some as yet undetermined military value. 2) In the course of their investigations in the fields of advanced technology, the Defense scientists and engineers must bring the problems of the Armed Forces before the broad scientific and technical community expressed in the terms of technical discourse. Second, we require objective scientific and engineering advice on contract research and development programs. Most of Defense RDT&E (research, development, test and evaluation) funds are expended on contract, and properly so. The advice of the Defense laboratories is critical not only because advice which is sensitive to the Government's interests must be available to management, but because that advice must be sensitive to the needs of the military users. Third, we need laboratory organizations to manage or help manage weapons systems development and test programs. Experience has been a harsh teacher and we are aware that it is not always wise or economical to try either to have a large project directed by a military user who does not understand whether what he wants is feasible, or to let the contractor be his own director, or to set up a small management office without technical support. Fourth, we need in-house laboratories as an essential part of the system of technical education for military officers. We recognize that without the actual experience of working in a laboratory it will not be possible to develop the cadre of technically proficient officers required for the operation of modern, rapidly changing armed forces, and for the understanding needed to set military requirements in a military situation in many ways unrelated to any previous one.[24]

While Brown's statement was made over 50 years ago, it is as valid and complete today as when it was originally made. Unfortunately, his guidance has often been ignored or forgotten. Had it been followed, DOD may have avoided some of the serious acquisition and technology problems that it has encountered during the past few decades.[25] It should be recognized that, while specifically calling out DOD laboratories, Brown was referring to the larger RDT&E program which involves DOD S&Es beyond what are now referred to as laboratories.

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[24] Statement of Harold Brown, Director of Defense Research and Engineering, "Federal budgeting for research and development," Hearings before the Subcommittee on Reorganization and International Organizations of the Committee on Government Operations, United States, 87th Congress, first session. Agency coordination study (pursuant to S. Res. 26, 87th Cong.), July 26, 1961, 7.

[25] See Christopher G. Pernin, Elliot Axelband, Jeffrey A. Drezner, Brian B. Dille, John Gordon IV, Bruce J. Held, K. Scott McMahon, Walter L. Perry, Christopher Rizzi, Akhil R. Shah, Peter A. Wilson, Jerry M. Sollinger, *Lessons from the Army's Future Combat Systems Program* (Santa Monica, CA: RAND, 2012).

At this point we can return to the question of whether or not the government can hire and retain the necessary S&Es. We will do so within the expectations set by Brown. These expectations will often intersect with, interfere with, or otherwise impact the interests of various communities. The following comments are based on the author's 50 year career in industry, government, and academia during which he saw the intersection, interference, and various other impacts from all sides. Regarding Brown's first role, there is a large community in the United States that performs this function. These S&Es are employed in industry, academia, not-for-profits, and government. In this role, some view DOD S&Es as colleagues, advocates, and sources of insight regarding DOD needs and interests. Others see DOD S&Es as competitors for DOD funds that could be better spent in their organizations. Regarding the second and third of Brown's roles, DOD S&Es tend to have different impact on those involved in marketing, management, or hands-on performance. Those involved in marketing focus on the matter of sales and sometimes resent anything that gets in the way of a sale. Those individuals often do not appreciate a government that has the technical competence and technical authority to raise serious questions regarding the merits of a proposed sale. As a result they have a tendency to operate in the political arena rather than the technical arena. Those involved in management sometimes seem conflicted in that they want successful programs, but can resent those "pesky" DOD S&Es who raise difficult questions regarding proposed programs and performance on programs in execution. However, these managers also appreciate the assistance and facilities that DOD S&Es can make available to them. Those external S&Es involved in hands-on performance tend to value the opportunity to deal with individuals in government that they view as technical peers.

Not surprisingly, the answer to the question of whether or not the government can hire and retain the necessary S&Es depends on where you sit. Those who answer the question negatively will often make the argument that the government cannot hire the required talent because it cannot pay adequately and it is too bureaucratic to recruit the necessary talent. The simplest rebuttal to this argument is to put the matter to an experimental test. We are concerned about the government's ability to recruit from among the nation's best scientists and engineers. We are also concerned about the ability to do this in mission-oriented environments. It would therefore seem reasonable to compare the stature of mission oriented organizations staffed by government S&Es and mission-oriented organizations staffed by non-government S&Es. The chosen organizations should be expected to be working on problems of comparable sophistication and difficulty where similar metrics would apply. At the high end of S&T where the recruiting should be most difficult, there are several metrics that are accepted to be indicative of staff stature and accomplishment. One such metric is staff recognition by election to the National Academies (Academy of Science (NAS), Academy of Engineering (NAE), and the Institute of Medicine (IOM)). A second metric is the staff peer reviewed scientific output. A third metric is the level of external recognition of the staff.

Since the matter of the government's ability to hire and retain highly regarded S&Es is broader than DOD, we will consider S&Es from three different federal government departments. Table 1 compares three in-house government research establishments staffed by federal S&Es, (National Institutes of Health (NIH), National Institute of Standards and Technology (NIST) and Naval Research Laboratory (NRL)), with several not for profit research establishments staffed by private sector S&Es (Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Jet Propulsion Laboratory (JPL), Los Alamos National Laboratory (LANL), Lincoln Laboratory (LL), and the Lawrence Livermore National Laboratory (LLNL)) regarding these metrics.

Table 1

Academy	ANL	BNL	JPL	LANL	LL	LLNL	NIH	NIST	NRL
NAE	2	1	4	1	1	1	1	7	8
NAS	4	7	1	3	0	1	52	7	3
IOM	0	0	0	0	0	0	46	0	0
Total	6	8	5	4	1	2	99	14	11
Approximate Staff Size	3000	3000	3000	7000	3000	8000	18,000	3000	3000
Nobel Laureates	1	0	0	0	0	0	5	4	1
Typical Annual Peer Reviewed Publications	1023	761	705	1526	N/A	1038	4305	350	957

Table 1: National Academies Memberships, Nobel Laureates, and Peer reviewed publications of Selected Research Establishments. NAE = National Academy of Engineering, NAS = National Academy of Science, IOM = Institute of Medicine).[26]

Clearly, all of the organizations shown in Table1 are fine research institutions of high stature. Furthermore, those staffed by federal employees (NIH, NIST, and NRL) have levels of staff recognition and productivity that are at least as high as the listed not-for profits. A comment on the use of the Nobel Prize as a metric is in order. The Nobel Prize is a rare event and is included simply to demonstrate that the institutions listed in Table 1 perform at a level where such recognition is possible. Most of the listed institutions have had significant involvement in work that was recognized by the Nobel Prize.

The argument that the federal government cannot hire from among the nation's best S&Es fails the reality test. The argument fails largely because it is based on the false premise that S&Es make employment decisions based primarily upon financial considerations. This is not true, especially for creative people. Such people view compensation in much broader than simple

[26] See "Member Profile Search," *National Academies of Science*, accessed on February 13, 2013, available at <www.nasonline.org/member-directory/?q=&site=nas_members&requiredfields=(member_membertype:Member|member_membertype:Emeritus|member_membertype:Foreign%20Associate)>.; "Members Directory, *National Academy of Engineering of the National Academies*¸ available at <www.nae.edu/Directory20412.aspx>; "General Directory," *Institute of Medicine of the National Academies*, available at <www.iom.edu/Global/Directory.aspx>; "Facts and Lists," *Nobel Prize*, available at <www.nobelprize.org/nobel_prizes/lists/>. Counts Laureates who were employed by their institutions at the time of selection. Science Citation Index Search for CY 2003 taken from Timothy Coffey, *Building the S&E Workforce for 2040: Challenges Facing the Department of Defense*, Defense and Technology Paper 49 (Washington, DC: Center for Technology and National Security Policy, July 2008).

financial terms. This broader view can be captured in a symbolic equation that we will call the *compensation equation*:

Compensation = Real Income + Psychic Income,

where

Real Income = F (salary, benefits, stock options, etc.),

Psychic Income = f (importance of program, impact on program, quality of facilities, stature of colleagues, quality of life, respect, etc.).

While the symbolic functions **F** and **f** cannot be written in analytical form, the compensation equation is quite real and forms the basis on which scientists and engineers, and many others, make employment decisions. If "real income" is too low relative to meeting needs of the individual, such as food, housing, education, retirement, among others, and with respect to other employment opportunities, then alternative employment will be sought. If, however, "real income" is above some threshold level, then "psychic income" begins to play an increasingly important role and can dominate the employment decision. The USG, especially DOD, has a great deal to offer regarding psychic income and, as a result, is able to recruit successfully from among the nation's finest scientific and engineering talent.

Table 1 demonstrates that the USG can recruit and retain individuals that can rise to high levels of performance and recognition. This table was created to prove a point. However, the metrics used to create Table 1 are not those that would apply to the majority of DOD S&Es since most of them do not engage in the type of activity that create the type of credentials that are tailored to the metrics of Table 1. Most of these individuals work in areas such as system development, systems engineering, systems integration, MRTF operation, and direct support of DOD acquisition programs. Collectively, these individuals have a deep understanding of every system in use by DOD. This includes the corporate memory, the skeleton closets, the successes and the failures. As such, they are an invaluable resource. Their credentials are attested to by the fact that, in spite of all its difficulties, DOD is recognized as having produced the world's most capable force. These individuals come into government and remain in government because they have done the calculus regarding their own compensation equation. If the government keeps real income above the necessary "threshold" and takes advantage of its ability to provide psychic income, it will continue to be able to hire from among the nation's best and brightest. The four roles described by Brown for DOD S&Es are especially powerful in this regard.

There has been some additional concern regarding whether DOD will be able to hire the needed S&Es in numbers sufficient to meet DOD's requirements. This matter was recently examined by the National Research Council which concluded that, with some possible exceptions, DOD should be able to meet its S&E staffing requirements.[27] Their optimism resulted from the

[27] Committee on Science, Technology, Engineering, and Mathematics Workforce Needs for the U.S. Department of Defense and the U.S. Defense Industrial Base; Division on Engineering and Physical Sciences; Board on Higher Education and Workforce; Policy and Global Affairs; National Academy of Engineering; National Research Council, *Assuring DOD a Strong Science, Technology, Engineering and Mathematics Workforce* (Washington, DC: National Academies Press, 2012), available at <www.nap.edu/catalog.php?record_id=13467>.

realization that DOD S&E requirement, while growing, is becoming an increasingly smaller fraction of the national S&E workforce. As a result, the S&E hiring by DOD will have little impact on the nation's S&E pipeline. This, however, raises another set of concerns that were recently discussed by Coffey and Ramberg.[28] Most important among those concerns is that of how DOD will maintain the necessary awareness of global S&T developments as its own S&E workforce becomes increasingly small relative to the growing global S&E workforce. Resolving this concern will require creative relationships among DOD S&Es and the larger community of S&Es. Maintaining a high quality DOD S&E workforce remains essential and can continue to be done.

[28] Coffey and Ramberg, *Globalization of S&T*.

VIII. Comment on the nuclear weapons laboratories

The principal topic of interest for this paper is the DOD S&E workforce associated primarily with the non-nuclear aspects of the national defense program. However, there is an initiative underway regarding the nuclear weapons laboratories that could impact the DOD S&E workforce (public and private) as well as the RDT&E program. This initiative warrants a brief comment.

Nuclear weapons are a key component of the national security program and there exists a cadre of S&Es that was created to support the development of this component of national defense. These S&Es are associated primarily with LANL, LLNL, and Sandia National Laboratory (SNL) which operate as Federally Funded Research and Development Centers under the Government Owned Contractor Operated (GOCO) concept. These laboratories form the RDT&E component of the nuclear weapons design program. The SNL is managed and operated by Sandia Corporation which is a wholly owned subsidiary of Lockheed Martin Corporation, while LANL and LLNL are managed by limited liability corporations (LLCs), both of which involve the Bechtel Corporation and University of California. The S&Es involved are not government employees but are employees of the several LLCs. Employing a total of about 12,000 S&Es, these three laboratories represent a relatively small, but influential component of the national security S&E workforce , and have played a critical role in the development and maintenance of the U.S. nuclear deterrent.

Nuclear weapons must be maintained in a state of readiness in perpetuity. Furthermore, the capability to design nuclear weapons must also be retained in order to deal with unexpected developments. The Department of Energy (DOE), through the National Nuclear Security Administration (NNSA), provides the nuclear weapons funding for the tri-lab complex. As the nuclear program moved from an R&D program to a maintenance-and-readiness program, concerns arose regarding the ability to retain the required S&E talent in the nuclear weapons laboratories. Dealing with this is further complicated by the fact that funding to the tri-lab complex from the NNSA has been declining. From FY06 through FY10, the total annual funding from NNSA for the three Labs declined by over $300 million, or about 7.5 percent. The laboratories accommodated to this reduction by increasing the work that they perform in the non-nuclear weapons arena. This has led to concerns that they are losing focus on the critical mission of nuclear weapons which is their raison d'être.

Some insight into this can be gained from a recent series of studies that attempt to identify some resolution to this conundrum.[29] The current trend seems to be to "evolve" these laboratories into national security laboratories. In that regard the DOE, DOD, the Director of National Intelligence, and the Director of Homeland Security have recently signed the *Governance Charter for an Interagency Council on the Strategic Capabilities of DOE National Laboratories as National Security Assets*. The National Research Council report specifically recommends that

[29] See Committee to Review the Quality of the Management and of the Science and Engineering Research at the Department of Energy's National Security Laboratories—Phase 1; National Research Council of the National Academies, *Managing for High-Quality Science and Engineering at the NNSA National Security Laboratories* (Washington, DC: National Research Council, 2012), available at <www.nap.edu/catalog.php?record_id=13367>; Frances Fragos Townsend, Donald Kerrick, Elizabeth Turpen, *Leveraging Science for Security: A Strategy for the Nuclear Weapons Laboratories in the 21st Century*, Report Number 71 (Washington, DC: The Henry L. Stimson Center, 2009); Libby Turpin, "Revitalizing the national security labs: Beyond the nuclear deterrent," *Bulletin of the Atomic Scientists* 69, no. 1 (2013), 53-61.

"Congress recognize that maintenance of the stockpile remains the core mission of the Labs, and in that context consider endorsing and supporting in some way the evolution of the NNSA Laboratories to National Security Laboratories as described in the July 2010 four-agency Governance Charter for an Interagency Council on the Strategic Capability of DOE National Laboratories."[30] In 2012, the tri-Labs names were changed from Nuclear Weapons Laboratories to National Security Laboratories. In furthering this evolution, Section 3148 of the 2013 National Defense Authorization Act requires that "The Administrator for Nuclear Security shall commission an independent assessment regarding the transition of the national security laboratories to multiagency federally funded research and development centers with direct sustainment and sponsorship by multiple national security agencies."[31] A report on this assessment is required by January 12, 2014.

While undoubtedly well intentioned, the developments described above could have potentially serious negative consequences for the nuclear weapons labs and for DOD. It is not clear how the required focus on nuclear weapons can be maintained in an environment where much of the laboratories work would be funded by others who will have expectations having little to do with nuclear weapons. Also, the idea of the laboratories, which are essentially private entities, being overseen by four separate government agencies needs to be rationalized. In addition, according to the studies mentioned above, the laboratories feel that they are being micro-managed by the NNSA. It is difficult to imagine that this perceived problem would lessen under the simultaneous oversight of four agencies. Perhaps the most problematic of all is the apparent absence of any recognition or consideration of the vastly larger RDT&E infrastructure and S&E workforce that DOD has put in place in the public sector and in the private sector to attend to the rest of the national defense needs. The U.S. national security system is a vast undertaking involving all segments of government and many segments of industry and academia. Nuclear issues are an important but small part of this undertaking. The evolution of the nuclear weapons tri-Lab complex to broad national security labs appears to be proceeding without any supporting analysis regarding its value to or impact upon the larger national security enterprise.

There is no doubt that the nation must maintain its nuclear weapons capability and accordingly preserve and nurture the human resources and expertise and technical capabilities needed to safeguard the NNSA core nuclear mission. This must be the primary focus for the tri-Lab enterprise. There is also no doubt that the nuclear weapons laboratories have made contributions to the broader national security program. This too should continue. However, in this latter role, they are a small part of the unambiguously successful current national security RDT&E infrastructure.

We must be sure that we do not "lose the forest for the trees" as we move forward on the matter of how to deal with the nuclear weapons workforce conundrum. While the nuclear weapons laboratories have a record of distinguished achievement, they are not unique in this regard; their uniqueness resides in their role in the nation's nuclear security posture. There are many other R&D establishments, inside the government and outside the government, with comparable

[30] Ibid., Committee to Review the Quality of the Management; National Research Council of the National Academies, *Managing for High-Quality Science and Engineering at the NNSA National Security Laboratories* (Washington, DC: National Research Council, 2012), 3, available at <www.nap.edu/catalog.php?record_id=13367>.
[31] H.R. 4310, *National Defense Authorization Act for Fiscal Year 2013*, Report 112-705, 112th Congress, 2nd Session, December 18, 2012, 568, available at <www.dtic.mil/congressional_budget/pdfs/FY2013_pdfs/AUTH_CRPT-112hrpt705.pdf>.

distinguished records of achievement that are also essential to DOD. Considerable caution should be exercised before diluting the tri-Lab expertise and focus on nuclear weapons and, as well, before causing a dilution of the capability of the existing DOD RDT&E infrastructure and the expertise of its associated S&E workforce.. Any rationalization of the Defense RDT&E program must take this larger view into account. This is especially true at this juncture where DOD anticipates a decade of declining funding.

IX. Conclusions

DOD is entering a period of great complexity and high uncertainty. In such times it is prudent to return to fundamental principles. One key principle that should be kept in mind is that warfare is not a matter to be left to the free market. In the cases of advanced weapon systems, platforms, and DOD advanced technology, an extensive commercial market place does not and cannot exist. For areas of national defense and warfare, societies have traditionally declared a government monopoly. In the United States, that monopoly is currently vested in DOD. In this capacity, DOD is responsible, subject to policy guidance from elected and appointed officials, for charting the future direction for the nation regarding national defense. While DOD will receive both solicited and unsolicited advice as it undertakes this task, it bears the full responsibility for the task. The quality of the undertaking will only be as good as the people employed by DOD. The outcome of the required calculus will depend on many factors, among which are:

- DOD's ability to recognize significant military, political, economic, scientific, and technical developments before they become obvious.
- Recognition that DOD's ability to determine the long-term directions is constrained by the fact that long range predictions are greatly hampered in the presence of complexity and uncertainty. The greater the uncertainty and the longer the prediction time horizon the more tenuous will be the predictions.
- DOD's ability to separate the best interests of the government from the interests of the multitude of parties vying for influence and for federal resources.

It is generally agreed that developments in science and technology will play an increasingly important role in military affairs. It is also understood that there are large ex ante uncertainties regarding the usage of new scientific and technological capabilities. These realities have significant implications regarding how DOD conducts its R&D programs and its major acquisition programs. They suggest that:

- DOD S&T program should be viewed as a vehicle by which the large ex ante uncertainties associated with new science and technologies are reduced and should be vigorously prosecuted accordingly.
- Major acquisition programs should be very conservative regarding the introduction of new technologies prior to the uncertainties associated with them being substantially reduced.
- The major acquisition programs and the S&T programs should be managed as separate tracks. Items in the major acquisition track should have a high expectation for success while what is done in the S&T track should have a high potential impact but a low expectation for transition. A vehicle for connecting the two tracks, when appropriate, needs to be in place.

The latter conclusion may seem counter intuitive to the success oriented DOD. However, the conclusion is reflective of reality. If a large portion of the S&T program transitions to major acquisition programs then, either the S&T program is too conservative and is not protecting

DOD's long term interests or the unresolved uncertainties associated with new technologies will be resolved in the major acquisition programs at great, yet avoidable, expense.

DOD in-house S&E workforce plays a key role in responding to the conclusions stated above. This workforce currently numbers about 130,000. These S&Es work in a variety of settings. About one-third work in DOD laboratories. Of the remaining two-thirds, the majority work at the MRTF, OTA, and in the Acquisition Workforce. Collectively these individuals form the government cadre of skilled scientists and engineers who strive to ensure that DOD can acquire, test and maintain advanced military systems and can develop the advanced military technologies needed for future use.

Many of today's military capabilities originated in DOD in-house activities and were transitioned to production through collaborations and sometimes competition among DOD in-house activities and out-of-house activities. In order for this to continue, DOD must conduct and manage its RDT&E programs such that DOD S&E workforce gains the hands-on experience that will attract and retain the talent necessary to fulfill the public trust. DOD mission itself provides the means to accomplish this objective. However, doing so requires a deliberate strategy regarding the balance of what is done in-house by DOD S&Es and what is done out-of-house by contractors of various sorts. Among the objectives of this strategy should be to:

- Provide the hands on experience needed to maintain in-house competence in science and engineering,
- Help sort out the promising technologies and technical directions from the less promising,
- Provide for competent internal government advocacy regarding the directions in which DOD should move,
- Provide the necessary competent "third party" through which DOD buyers can determine a fair and equitable price in the bargaining process associated with the bi-lateral monopoly that exists between DOD and the defense industry.

For advanced weapons systems, platforms, and technology, the role for in-house S&Es suggested above requires a high degree of scientific and technical knowledge and authority as well as an understanding of what DOD needs and how DOD, as an institution, operates. If the government is to play this role, it must be able to hire and retain the scientific and engineering talent needed to accomplish this function. A metrics-based comparison of three government R&D institutions staffed with federal S&Es with six not-for-profit R&D institutions staffed with contractor employees demonstrates the federal S&Es are of at least as high stature and recognition as the not-for-profit institutions. This demonstrates that one can run high quality R&D establishments inside the government with federal S&Es and outside of the government with non-federal S&Es. Therefore, DOD can certainly hire the necessary S&E talent if it takes the appropriate measures. Its strategy for doing so must consider providing hands-on experience to the government S&Es. This involves the S&Es: investigating rapidly changing fields of science and engineering, bringing the problems of the Armed Forces before the broad scientific and technical communities in terms of technical discourse, providing objective advice regarding contract research, and development programs, understanding of and sensitivity to the government's interests, helping manage weapons system development and test programs, assisting the military user to understand what is technically feasible and assisting in the technical education for

military officers. The strategy must also include developing strong ties with colleges and universities that involve joint research and work assignments for students and faculty at DOD R&D facilities. This will go a long way towards creating the lasting bonds between DOD and the larger scientific and technical community that are needed to sustain the DOD S&E workforce in the long term.

Regarding the nuclear weapons component of national defenses: nuclear weapons must be maintained in a state of readiness in perpetuity. As we move forward on the matter of how to deal with the conundrum that, on the one hand, the tri-Lab nuclear workforce is a key aspect of the nuclear deterrent, but on the other hand the NNSA nuclear weapons funding to the tri-Lab complex is decreasing, we must be sure that we do not "loose the forest for the trees" While the three nuclear weapons laboratories have a record of distinguished achievement, they are not unique in this regard; their uniqueness resides in their role in the nation's nuclear security posture. There are many other R&D establishments, inside the government and outside the government, with comparable distinguished records of achievement that are also essential to DOD. Considerable caution should be exercised before diluting the tri-Lab expertise and focus on nuclear weapons, and caution should be exercised as well, before taking action that causes dilution of the capabilities of the existing DOD RDT&E infrastructure and the expertise of its associated S&E workforce. Any rationalization of the Defense RDT&E program must take this larger view into account. This is especially true at this juncture where the coming years are likely to be difficult ones regarding maintaining the national security enterprise, as DOD anticipates a decade of declining funding. This is a topic which requires analysis of possible unintended consequences on the current and effective nuclear and non-nuclear components of the national defense R&D programs and further study is in order.