Defense Conversion and the Future of the National Nuclear Weapons Laboratories

Judith Reppy and Joseph Pilat, eds.

Proceedings of a Conference Held at
Cornell University
Ithaca, NY
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The Peace Studies Program was established at Cornell in 1970 as an interdisciplinary program concerned with problems of peace and war, arms control and disarmament, and more generally, instances of collective violence. Its broad objectives are to support graduate and post-doctoral study, research, teaching and cross-campus interactions in these fields.

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PREFACE

The end of the Cold War has altered dramatically the context in which the national nuclear laboratories operate. For nearly fifty years, the three laboratories—Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Sandia National Laboratory—have had as their prime responsibility the design and testing of the nation's nuclear weapons. With the collapse of the Soviet Union, the planned reduction in the nuclear arsenals on both sides, and the fall in spending for national defense, the laboratories face a redefinition of their mission and smaller budgets. The nuclear threat has not disappeared, but it no longer provides a rationale for the size and scope of defense activities that were supported at the laboratories in the past.

Is there a new mission for the laboratories that would justify the national investment in them? Over the years the laboratories have built up great technical capabilities in their physical facilities and highly trained workforce. Can their scientific and technical resources be applied to strengthening the technology base of the civilian economy and improving U.S. competitiveness in international markets? What other missions might be well-served by the laboratories' capabilities?

With their entrenched bureaucracies and inexperience in dealing with the commercial world, the laboratories may not be well suited for the types of economic problems that have risen to the top of the policy agenda. And whereas they had an undisputed monopoly in the design and development of nuclear weapons, other organizations, governmental and private, are competing for the new economic tasks. In short, there is no lack of national challenges, but it is not clear whether the laboratories' resources can be deployed to address them effectively.

The Peace Studies Program of Cornell University sponsored a workshop in Ithaca on October 1-2, 1993 to discuss these issues. Participants came from all three national laboratories, Cornell and other universities, government agencies and other Washington-based organizations. The workshop was organized into three sessions that focused on defining the nuclear mission, planning for conversion, and technology transfer issues. Background papers were prepared by Cornell authors and discussed by panels of outside experts, followed by general discussion. Three Cornell graduate students served as rapporteurs: Charles Nakhleh (Session I), Rachel Weber (Session II), and Anand Prakash (Session III).

Over the course of a day and a half, many issues were aired and debated, and although we did not seek to reach consensus, convergence around certain points did occur. It was generally agreed that an important, albeit smaller, nuclear weapons mission remained for the laboratories; that although there are national problems—such as energy security or the environment—which the laboratories are equipped to address, the political will to provide large-scale funding for them may not exist; and that current technology transfer activities, while beneficial in the short-run, will not supply a long-run raison d'être for the laboratories. On other issues there was less agreement, but the discussion throughout was lively and informative.

This Occasional Paper brings together the background papers with the summaries of the panel presentations and open discussion prepared by our rapporteurs. We have also included as Appendix A a short essay by Hans Bethe on the subject of conversion of the national laboratories that grew out of remarks that he made at the workshop; an edited version of this essay was published on the op-ed page of the *New York Times* on December 6, 1993. The program for the workshop and a list of participants can be found in Appendix B.

We want to thank all the participants for their thoughtful contributions to the workshop discussion. We also owe thanks to the rapporteurs, and to Elaine Scott and Sandra Kisner of the Peace Studies Program's staff, whose efficient and cheerful help made the workshop possible. Funding for the workshop came from program funds of the Peace Studies Program.

PANEL I: WHAT IS THE NUCLEAR MISSION?

The Future of Nuclear Weapons: Implications for the Laboratories

Joseph Pilat and Lawrence Scheinman

The primary mission of the nuclear weapons laboratories during the Cold War was research, development and testing of nuclear weapons, and that mission largely shaped the laboratories. It is, therefore, difficult to disassociate the future of the laboratories from the future of the nuclear weapons mission. That mission, and the longer term role of nuclear weapons, are changing, and these changes will affect the laboratories and will open opportunities for new directions, including defense conversion. The scope and nature of those opportunities will be defined in the first instance by the evolving nuclear mission.

The first question, then, has to do with the range of likely futures for nuclear weapons in the post-Cold War period. Is it possible to imagine a world without nuclear weapons as advocated in a recent Pugwash book?[1] Will a growing aversion to nuclear weapons lead to their elimination? Or will the instabilities of the "new world order," from the fate of Russia to the proliferation of nuclear weapons by regional hegemons and rogue states, ensure that nuclear forces have a future role? Bearing in mind the extent of our surprise at the rapid end of the Cold War and our limited ability to anticipate international political change, we should approach this question with some humility.

The predominant, but not uncontested view is that in the past, nuclear weapons served to minimize the dangers of global war. The risk of escalation from regional to global nuclear conflict restrained the behavior of the United States and the Soviet Union by inspiring cautious conduct. Nuclear weapons were perceived in the United States as useful for deterring conflicts with, and influencing the behavior of, the Soviet Union and other nations; for preventing nuclear

[1] Joseph Rotblat, Jack Steinberger and Bhalchandra Udgaonkar (eds.), *A Nuclear Weapons Free World: Desirable? Feasible?* (Boulder, CO: Westview Press, 1993).

attacks on US or allied territory and forces; and for deterring certain non-nuclear aggression, especially a massive conventional invasion of Western Europe.

Whether or not deterrence policy actually deterred a hot war over the last decades and whether deterrence required the vast numbers of nuclear weapons acquired during the Cold War are debatable and debated questions. Some contend that the answer to these questions, or at least the first, is yes. Others argue that the success of deterrence was never fully assured at any level of forces.[2] By their very nature, these questions may be unanswerable, but they do continue to influence the debate about the future of nuclear forces.

Uncertainties regarding the future role and purpose of nuclear weapons, and consequently the nature and extent of future nuclear forces, are readily identifiable. At a minimum they include:

- the impact of the end of the Cold War on the concept of deterrence as it relates to security policy, and as a consequence on political perceptions of, and budgetary pressures on, nuclear weapons; and
- an unpredictable international security environment, including uncertainties about the fate of Russia and the future nuclear plans of China, France, and the United Kingdom.

However the issue of the future of nuclear weapons may be decided, for the foreseeable future additional uncertainties will arise from the attempt to adjust strategic doctrine and force structure to new realities:

- the continuation of difficulties in operationalizing deterrence policy, which will be circumscribed in any case;
- the establishment of targeting requirements and their relationship to deterrence;
- the absence of a sound basis for determining the weapons requirements of deterrence, since the minimum number of nuclear weapons needed to deter a nuclear attack are dependent on specific countries and circumstances and probably unknowable; and

[2] For two representative views in this debate see John Mueller, "The Essential Irrelevance of Nuclear Weapons: Stability in the Postwar World," *International Security* 13 (Fall 1988), and a response by Robert Jervis, "The Political Effects of Nuclear Weapons: A Comment," ibid.

- the uncertainty of prospects for strategic and theater defenses and their implications for stability.

At this time, given these and other uncertainties, it is not possible to predict whether the nuclear danger will rise or fall. The danger of nuclear conflict as perceived during the Cold War has certainly declined dramatically. Nuclear threats remain, but they differ from those of the last four decades. During the Cold War, the fear of a nuclear war with the Soviet Union was the overriding concern. The prospect of nuclear war with China and other threats were secondary.

In the post-Cold War world, on the other hand, the perception and definition of nuclear threat has expanded to include:

- nuclear proliferation and terrorism, driven by the expansion of knowledge, technology and resources, as well as by changing incentives resulting from the end of the Cold War;
- "loose nukes" in the former Soviet Union, with the possible political disintegration of Russia (and perhaps eventually of China);
- unauthorized or accidental nuclear weapon use;
- risk of access to growing stocks of special nuclear materials as a consequence of disarmament and dismantlement (and commercial nuclear activities); and
- environmental damage and risks to public health of production, dismantlement, etc.

Unless a hostile Russia emerges from the former Soviet Union, a nuclear war with Russia or other Soviet successor states is no longer seen as the principal threat. The central issue now is whether nuclear weapons are necessary to respond to the perceived new threats. While nuclear weapons have no plausible role in dealing with accidents, terrorism or environmental problems, the question is still very open as to whether they have a role in responding to the emergence of a new nuclear state, not to speak of their continued relevance in the face of a possible hostile Russian successor to the former Soviet Union.

There seems to be wide agreement that the primary role of US nuclear weapons should continue to be deterrence of nuclear use by others. For the immediate future, simply by virtue of capability rather than intention, the arsenal of the former Soviet Union, especially in Russia, will be the principal object of a deterrent force. It alone has the ability to threaten the national survival of the United States, or its allies and friendly countries worldwide. Threats from China or other nuclear weapon states or proliferants are much more problematic, but cannot be entirely discounted. In the view of some, this is a persuasive reason for justifying the continued presence of nuclear weapons.[3]

The future of extended deterrence and associated assurances is uncertain, but it is supported in the US and among US allies. Other possible but very controversial roles for nuclear weapons have been put forward on the basis of Cold War rationales, including deterrence of biological/chemical warfare and conventional attack; and assuring US military supremacy or global influence. More far-reaching new missions such as deflecting asteroids on a collision course with earth also have been raised. Targeting requirements as well as future force structures and sizing will be dependent on whether these missions are agreed by policy makers to be legitimate and necessary functions of nuclear weapons.

A range of views on how to approach the changing world order has emerged. Paul Nitze, for example, reflecting a cautious and restrained approach, has called for conservative adjustment of nuclear strategy on the ground that while "rapid and dramatic change has . . . raised hopes for a more peaceful world and for a lessening of the nuclear danger," a nuclear-free world is not possible because ". . .nuclear weapons cannot be disinvented; their existence will continue."[4]

In a changing world, he argues, the United States should maintain a strategic arsenal whose size and effectiveness is gauged by the arsenal of the former Soviet Union; and it should maintain a strategic reserve equal to the arsenals of all other nuclear powers. In addition, the United States should dramatically reduce nonstrategic nuclear weapons (except for air-delivered weapons in Europe), and change nuclear targeting to focus on conventional forces and installations (following the example of the Gulf War, where communications, air defenses, and electric power transmission grids were targeted). The United States should, however, seek to replace

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[3] See Paul Nitze, "Keep Nuclear Insurance," *Bulletin of the Atomic Scientists* 48 (May 1992), pp. 34-36; and Committee on International Security and Arms Control, National Academy of Sciences, *The Future of the U.S.-Soviet Nuclear Relationship* (Washington, DC: National Academy Press, 1991), pp. 14-18 and passim.

[4] Nitze, "Keep Nuclear Insurance."

nuclear missions with conventional capabilities where possible and to restructure nuclear forces to improve stability, survivability and flexibility.[5]

Another approach has been put forth by Ashton B. Carter, William S. Perry and John Steinbruner, who, in their concept of "cooperative security," suggest a more radical departure from the past. They argue that:

> At hand with the end of East-West confrontation is the prospect of radical de-emphasis of nuclear weapons in the security conceptions of the major powers. In this vision nuclear weapons would stand in the background of the military establishments of the major powers rather than in the foreground. . . . Doctrines covering residual nuclear forces. . .would foresee retaliation only. . . .[6]

In their view, with the end of the Cold War it is "possible to envision a dramatic deemphasis of the role of nuclear weapons in security, smaller and simplified arsenals, and enhanced safety and security—all pursued cooperatively."[7] They do not see doctrinal transformation occurring by itself, however compelling its logic. Rather, change along these dimensions is something that must be promoted and nurtured.

In addition to arguments for relegating nuclear weapons to a background role in international security, or a strategy of "nuclear disengagement," they offer a prescription for "cooperative denuclearization," which includes the reduction of active arsenals and the dismantling of surplus nuclear weapons (in part to deal with the problems arising from the breakup of the Soviet Union), enhancement of the safety of remaining nuclear weapons, and nonproliferation efforts.[8] From their perspective, these actions constitute a valid response to an emerging nuclear security problem that displaces the nuclear concerns of the Cold War, namely, removing the "nuclear

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[5] Ibid., pp. 34-35.

[6] *A New Concept of Cooperative Security*, Brookings Occasional Papers (Washington, DC: The Brookings Institution, 1992), p. 12.

[7] Ibid., p. 19.

[8] Ibid., p. 11-20.

weapon overhang" of the Cold War while ensuring that nuclear capabilities and weapons do not spread. And, they argue, these actions require a strategy of cooperative resolution.[9]

Going beyond traditional arms control and disarmament rationales, they advocate a de-emphasis of nuclear weapons for its perceived nonproliferation benefits. There is today an increasing appreciation that proliferation is a problem to the extent that countries value nuclear weapons as symbols of power and prestige. In presenting their case, Carter and his colleagues emphasize that:

> nuclear weapons still hold attractions for aspiring lesser powers, even though they no longer serve compelling needs for the great powers. Deemphasizing nuclear weapons in their own security thinking is a necessary, if not sufficient, step by the great powers toward inducing others to deemphasize them.[10]

Similar, and even more forceful arguments have been made by several nonproliferation authorities including McGeorge Bundy, Lewis Dunn and Lawrence Scheinman. They argue that in the interest of enhancing nonproliferation the United States and other nuclear weapon states should reduce their nuclear weapon forces to an absolute minimum consistent with the new context of national security and emphasize through public diplomacy and other means that nuclear weapons are neither useful nor of any value.[11]

Many of the specific proposals embodied in these approaches are in one form or another already being pursued by the United States and other nuclear weapons states in conjunction with the significant arms reductions agreed to in recent years (which, in most cases, are yet to be implemented). Only a short time ago the more far-reaching of these proposals, and the approaches themselves, would have been regarded as dramatic if not radical, but today they are seen in many

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[9] Ibid., p. 20.

[10] Ibid., p. 13.

[11] See McGeorge Bundy, "Deterrence in the 1990s: What Can the Past Tell Us?" Center for Technical Studies on Security, Energy, and Arms Control, Lawrence Livermore National Laboratory, Report CTS-26-90 (April 19, 1991); Lewis Dunn, "Global Order in an Era of Proliferation," in Rose Gottemoeller, ed., *Strategic Arms Control in the Post-START Era* (London: IISS, 1992); and Lawrence Scheinman, "The Non-Proliferation Treaty: On the Road to 1995," *IAEA Bulletin: Quarterly Journal of the International Atomic Energy Agency* 34, 1 (1992), pp. 33-40.

quarters as only modest and limited responses to the changes in the world and to the genuine nuclear problems of the future, especially nuclear proliferation.

In this context, others have gone even further toward promoting the objective of a world without nuclear weapons. While recognizing an emerging proliferation problem in the post-Cold War era, they argue for delegitimization or devaluation on even broader grounds:[12]

- nuclear deterrence is immoral;
- nuclear weapons are illegitimate; and
- nuclear weapons have unacceptable social, economic and other consequences.

One proponent of this view, Daniel Ellsberg, argues that nuclear weapons should be stripped of their special status and symbolism and be wholly devalued and delegitimized. In Ellsberg's words, the

> era of nuclear threats should end with the Cold War, but that is not what is happening today. . . . What is required is a dramatic and comprehensive package of coordinated changes in policies and programs, changes expressing the desire of our society and government to make a decisive shift in our relation to nuclear weapons.[13]

Ellsberg refers to his comprehensive and coordinated approach to denuclearization as "Manhattan Project II," which he contends

> should undo the legacy of the first; reduce nuclear weapons to near zero and free the earth from the danger of nuclear war—as completely as possible—by the end of the century.[14]

This initiative, along with other similar approaches such as the earlier referenced Pugwash initiative, begins with but goes well beyond traditional arms control and includes:

- a comprehensive test ban;
- an end to fissile material and warhead production;

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[12] See, for example, Daniel Ellsberg, "Manhattan Project II," *Bulletin of the Atomic Scientists* 48 (May 1992), pp. 42-44; William Epstein, "And Now—The U.N. Century," *Bulletin of the Atomic Scientists* 48 (May 1992), pp. 22-23; and Theodore B. Taylor, "Just Unplug Them," *Bulletin of the Atomic Scientists* 48 (May 1992), pp. 27-28.

[13] Ellsberg, "Manhattan Project II," p. 43.

[14] Ibid., pp. 42-43.

- the reduction and elimination of nuclear weapons (dismantlement and destruction);
- an end to R&D on nuclear weapons;
- an end to production of nuclear delivery vehicles and a ban on ballistic missiles;
- a ban on the use of nuclear weapons (no first use);
- the conversion of nuclear installations;
- the productive employment of nuclear scientists and technicians to avoid a "brain drain";
- reduced military expenditures; and
- effective policies for nonproliferation, perhaps including military measures.

Many of these actions can be undertaken in pursuit of policies other than total denuclearization, and are in fact currently on the negotiating agenda of the United States and other nuclear weapon states. Were they all to be realized, it would constitute a revolution in the security sphere. Such a world would have appeared an impossible dream only a few years ago, but there is growing support for the belief that it is realizable now or in the near future.

As already suggested in our earlier discussion, this belief does not go unchallenged. Arguments that cast doubt on the prospects of achieving a denuclearized world in the foreseeable future are well known and include:

- the genie is out of the bottle (nuclear weapons cannot be disinvented);
- nuclear weapons have fostered stability and security;
- future regional hegemons and rogue states must be deterred by nuclear weapons;
- the elimination of nuclear weapons is not feasible unless war is abandoned as an instrument of policy; otherwise a nuclear weapon ban could mean that the world will be confronted by the prospect of highly destructive conventional wars.

Have such arguments lost their validity? In this changing world we need to reassess all of these arguments. One thing is certain, however; <u>the devaluation of nuclear weapons has already occurred</u>. This is demonstrated by recent unilateral and negotiated arms reductions, by the irrelevance of nuclear weapons to the changes sweeping the world, and by the Gulf War, where the successes of conventional firepower apparently signalled "the shape of things to come" in terms of desired future military capabilities.

Despite these developments, the prospect of a world without nuclear weapons in the foreseeable future does not appear great, and certainly is not imminent. It is fair, however, to ask whether denuclearization nonetheless serves as a useful future goal and guide. Many believe so; and increasingly the focus is turning to such questions as how, with what speed, and with what alternative security structures in place one moves down the path of delegitimization. While the nature of deterrence is changing, and the role of nuclear weapons is declining, if nuclear weapons are delegitimized too quickly, an element of policy that has in the past fostered security and stability may be undermined without an alternative being in place.[15] Delegitimization may in fact outstrip the actual declining role of these systems.

Does this pose a problem? Yes, to the extent that not all relevant states share the view that nuclear weapons have no real value. If nuclear weapons are declining in importance in the industrialized world, the situation is less clear in the developing world and in parts of the former Soviet Union. One conclusion that states like Iraq and Iran may draw from the Gulf War, for example, is that nuclear weapons may be necessary for the security of states that cannot deploy advanced conventional weapons. North Korea seems to have concluded that its survival as a Communist monarchy is dependent on nuclear ambiguity if not nuclear weapons themselves. And, however dubious in the eyes of outsiders, one conclusion that arose and still has currency among important elements of the political elite in Ukraine seems to be that nuclear weapons may serve Ukrainian security vis-à-vis a possible Russian interest in reestablishing a Russian empire. This conclusion resulted in delays in reaching, and continuing concern about, the settlement on the disposition of nuclear arms inherited by Ukraine. Ukrainians and others have also seen nuclear weapons as a badge of international status: with them we are listened to, without them we will be ignored. These and other potential like situations define the nonproliferation and international security challenges for the 1990s, in which the decisions and behavior of existing declared nuclear weapon states play a significant part.

To return to our earlier theme, while the roles and missions of nuclear weapons are declining as the Cold War conditions that defined those roles and missions disappear, and while the numbers of nuclear weapons are diminishing as a consequence of continued arms control and

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[15] On this theme see Lawrence Scheinman, "The Role of Multilateral Regimes in Non-Proliferation," Symposium on World Security and Weapons Proliferation, *Transnational Law and Contemporary Problems* 2, 2 (Fall 1992), pp. 569-586.

disarmament agreements that reflect those changed conditions, it is unlikely that we will witness a world without nuclear weapons in the foreseeable future. How the declared nuclear weapon states deal with nuclear weapons in the longer run will be determined in part by the behavior of existing and expected proliferants -- their compliance with the norm of non-proliferation and their acceptance of binding and internationally verifiable nonproliferation undertakings will have a bearing on how low reductions in the arsenals of nuclear weapon states ultimately will go. As long as nonproliferation makes progress toward comprehensive, global achievement, nuclear disarmament can proceed. This is hardly surprising, because there has been an historical relationship between nonproliferation and arms control.

Even without a nuclear weapon free world, however, nuclear weapons will be reduced in both numbers and roles, less visible and even less important in international affairs than previously. This situation will have implications for the nuclear weapons laboratories and the rest of the nuclear weapons complex. It now appears that their focus will be stewardship. According to John D. Immele and Philip D. Goldstone, in the new environment the laboratories must

> provide for the stewardship of the ongoing stockpile. . . . The emphasis of the program will be to assure adequate safety, security, reliability and flexibility of. . . remaining forces. . . . There will be a permanent shift in emphasis within the complex from production of nuclear materials to management and control of nuclear materials and waste.[16]

In addition to dealing with the dismantlement of nuclear weapons, the storage and conversion or disposal of discharged nuclear materials, and waste management, stewardship will in practice involve efforts to extend the life of existing nuclear weapons so long as they are required for deterrence.

The most important challenge will come at some time in the next century, when the life of current systems can no longer be extended. Will the production of new nuclear weapons be required, or will the politics of security and stability have taken us beyond the need for them? Will the capacity to produce them, if needed, be in place? Until then, there will be no or only limited safety and security upgrades of nuclear weapons. And there will be no nuclear weapon

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[16] "Redefining the U.S. Nuclear Weapons Program and the DOE Nuclear Weapon Complex," *Los Alamos Science* 21 (1993), p. 45.

modernization in the United States, and perhaps the United Kingdom and Russia. The intentions of China and France are uncertain in this respect. It is widely believed that any nuclear weapons that remain after arms reductions are implemented should have the attributes of controllability (improved C^3I), reliability, and safety. US forces will have these qualities, but they will not be optimized given the current climate.

While these trends are becoming more apparent, their implications for the nuclear weapons laboratories are by no means as clear. At present there are no programs to develop new nuclear weapons, and great uncertainties and differences surround any possible future requirements. This situation provides the context for serious examination of the laboratories' future. In closing this introductory inquiry on the nuclear mission, we offer the following questions for discussion:

- Does the uncertain nuclear future argue for continuity and evolution or for more dramatic change?
- What is the meaning of "stewardship" in terms of laboratory programmatic activity in the future and during a transition period?
- Will stewardship, as is now anticipated, become the primary national security mission of the laboratories? Does this ensure a continuing technical competence and capability for weapons research and development? To what extent is such competence and capability a priority? Are two design laboratories necessary or justified in this context?
- What does stewardship mean for the laboratories' role in basic science? The maintenance of levels of efforts? Security and secrecy requirements and the manner in which they are implemented in the future?
- Which of the old nuclear weapons programs can be converted? Do the different laboratories have differing prospects in this respect?
- Can such conversion as is deemed desirable and feasible be undertaken in a way that preserves core nuclear competencies while obtaining important or unique commercial benefits and promoting US economic competitiveness?
- Will the laboratories play an increasing role in dealing with emerging problems, from nonproliferation and weapon dismantlement and plutonium disposition to energy and the environment?

- Of particular importance in the area of emerging issues, what role can the laboratories play in support of nonproliferation (up to now primarily nuclear-weapons related, but to be conceived more broadly to embrace other weapons of mass destruction and associated delivery systems)?
- In what areas and ways can existing or potential laboratory capabilities be brought to bear on behalf of nonproliferation objectives? What of their role in export control monitoring? What of end-use verification and enhanced verification, including environmental monitoring to ensure that foreclosed activities are not taking place or that legitimate activities are fully reported?
- What is the laboratories' role in the verification of a fissile material production cutoff, as well as monitoring a comprehensive test ban by the weapons states, along with the dismantlement of nuclear weapons and the safe and secure storage of disassembled warhead nuclear material?
- What are the prospects of reaching beyond weapons to roles in energy development and environmental monitoring and protection, and whether and how the laboratories can be mobilized as a resource to these ends?
- Will a decline in the laboratories' traditional mission affect their ability to contribute to these missions?
- In this context, are the "customers" of the laboratories changing? How can the technical, analytical, multidisciplinary and organizational skills that are the hallmarks of the laboratories serve new national missions and objectives?

PANEL I: WHAT IS THE NUCLEAR MISSION?

Chair: Kurt Gottfried, Cornell University

Background Paper: Joseph Pilat and Lawrence Scheinman, "The Future of Nuclear Weapons: Implications for the Laboratories"

Panel: Paul Brown, Lawrence Livermore National Laboratory
Paul Cunningham, Los Alamos National Laboratory
Richard Garwin, IBM Fellow Emeritus
Jon Medalia, Congressional Research Service

PANEL PRESENTATIONS

Paul Brown began his remarks by noting that even though the Cold War is over and the arms race has become a race to disarm, dangers persist in the world. Ethnic strife in eastern Europe, turmoil within and around Russia, and nuclear proliferation in the former Soviet republics and elsewhere, all combine to paint a confusing picture indeed. In this uncertain new world, he said, the U.S. will need to reconsider the role of nuclear weapons, and attempt to answer anew questions about the relevance of deterrence, the future of arms control, and the minimal levels of nuclear forces necessary.

The new duty of the weapons labs is that of steward to a much reduced stockpile with fewer types of weapons. Their challenges include maintaining the safety and reliability of what's left, without nuclear tests; dismantling excess warheads safely and rapidly and helping the Russians to do so, too; and dealing with the problems of proliferation. By applying their talents to civilian projects, they will address important national problems, while maintaining the scientific skills that may be needed to respond to future defense requirements.

Picking up on Paul Brown's remarks, **Paul Cunningham** stated that there is a strong lab role in warhead dismantlement and the disposition of nuclear materials. He also noted that "stewardship" will extend over a period of 30-50 years, and that we have no experience with the behavior of weapons over such a long time.

In Cunningham's view, the weapons complex must maintain a "rebuild capability" for some period of time at least. As far as the labs themselves are concerned, they need a "flywheel" mission—that is, a large and dominant mission with strong national backing—to justify their existence. Nuclear weapons used to fill this role. What will in the future?

Richard Garwin began by raising a simple question: Will the labs be able to make even old weapons in the future? He argued that while continued testing may be desirable on a purely technical basis, politically it would detract from U.S. security and would thus contribute "a net negative" to the security balance sheet.

Finally, Garwin asked: Do we need both weapons labs?

Jonathan Medalia noted that several factors—a halt to U.S. nuclear tests, a halt to new warhead designs, a decline in the number and types of weapons, and general budget cuts—impose a ceiling on the labs' nuclear mission, while others—a need to maintain some weapons and dismantle others, to clean up the weapons complex, and to promote nonproliferation—set a floor under this mission. This leaves the labs' nuclear mission relatively insensitive to changes in the nation's nuclear mission.

The DOE will request funds from Congress for new facilities to carry out its goal of stewardship, but it will be difficult for Congress to understand, let alone pass on, these requests unless they are presented as a single package with each facility linked to the aspect of weapons safety and reliability it addresses.

Several questions remain: In the absence of activity in warhead development and testing can the DOE actually attract and retain quality people for the stewardship mission? And how can Congress be sure—in the absence of testing—that the country is getting what it's paying for? Will the experts of the future even be experts?

SUMMARY OF DISCUSSION (Charles W. Nakhleh):

Thematically, the participants' remarks divided into three main areas: the present and future of U.S. nuclear weapons; the role of the labs in that future; and the constraints under which the labs will be forced to operate.

I. U.S. Nuclear Weapons—Present and Future

There was surprisingly little debate about the purpose of the nuclear stockpile, a topic that dominated the Cold War debate. This was not for lack of effort by the presenters. Pilat and

Scheinman demonstrate in their paper that reasonable men can disagree in their opinions of the utility, numbers, diversity, and targeting of U.S. nuclear weapons. They emphasized time and again in their presentation that uncertainty regarding the control and management of the Soviet stockpile, and the impossibility of predicting where and whether new nuclear dangers might suddenly appear, argued in favor of retaining an unspecified (but lower) level of strategic nuclear weaponry as a hedge against the future. This point of view was widely endorsed. Everyone agreed that some "deterrent" was necessary—but no one could say precisely at whom or to what ends this deterrent was to be directed. Perhaps the question is currently unanswerable.

Even the language the participants used differed strikingly from that of days gone by. The revised nuclear lexicon now relegates antiquated terms like strategic parity, throw weight, and first-strike capability to the footnotes, and replaces them with fresh new nouns like "core competence" and "rebuild capability." But these bare terms need fleshing out. Undoubtedly, many more hours of discussion and reams of paper will be required to determine exactly how many scientists, engineers, and facilities constitute an adequate "core competence" or an effective "rebuild capability." For example, will the U.S. need to be able to build on short notice one, one hundred, or one thousand nuclear-tipped missiles?

One hard fact did cut through the vagaries, though, and commanded widespread acceptance throughout the discussion: the stockpile is declining rapidly in both numbers and varieties of warheads, and will in all likelihood decline further. The question is, Where is the best place to stop?

II. The Role of the Labs

Accepting that the U.S. will retain a much-reduced stockpile into the next century, the panel quickly turned to the role of the labs in maintaining the warheads. Here, opinions diverged.

All concerned agreed that the labs have a large role to play in the safe, environmentally secure dismantlement of both the Soviet and American warheads scheduled for removal from their respective stockpiles. This will require a large R&D investment not only in attempting to dispose of the hundreds of tons of highly enriched uranium and plutonium that will result but also in more mundane matters. An example is the W48 artillery shell: new environmental regulations have forced the DOE plant to adopt a different approach in dismantling the warhead—an approach which resulted in a small plutonium release. Livermore, which designed the W48, was called upon to assess the problem and to develop a safer approach, illustrating thereby the importance of close oversight by the designing lab in the dismantlement of a weapon. Such safety problems have stimulated further research into environmentally safer technologies for warhead dismantlement, research that takes time and money.

The theme of environmental responsibility pervaded the discussion. This is a new factor in the weapons-complex's collective thinking. Numerous examples of the DOE's tendency to leave untidy footprints crept into the participants' comments throughout the workshop; and all present realized that this is no longer acceptable practice. The participants from the labs agreed that ensuring environmental safety at all steps of the dismantlement process will require a not insignificant fiscal and public relations investment on the government's part.

A word much in vogue during the discussion was "stewardship." Differing interpretations were offered as to what this term means precisely, but most seemed to agree that it includes —but may not be limited to—the following:

- The safe and secure management of a significantly smaller U.S. stockpile without further nuclear testing.
- No new warhead development or production.
- The retention of a "core competence" on the part of the labs to study and adequately accommodate the effects of aging on a nuclear weapon; to improve or at least maintain the safety of a nuclear weapon; and, if need be, to remanufacture carbon copies of current warheads.

The meaning of the last point was contested vigorously without a decisive outcome. Several participants from the labs disputed the notion that nuclear weapons technology could be frozen safely and securely without a large erosion in the labs' ability to perform the duties included under the rubric of core competence. What will happen 30, 40, or 50 years down the line when we have a bunch of ancient weapons on the shelf? Will we be able to guarantee their safety or even their workability? Will the currently first-rate scientists in the weapons complex remain in top form, or see their skills atrophy for want of exercise? Will they even remain in the weapons business? On the other hand, came the retort, the labs will be perfectly free in the future to test every weapon component except an active pit—and this should adequately ensure the stockpile's safety for years to come.

From Congress's point of view, a "stockpile stewardship program" could require sizable appropriations for future storage and dismantlement facilities—a difficult thing to bring off in these tight-fisted days. Maintaining weapon reliability and safety in a CTB environment will be a congressional goal; but there is also concern on the Hill that hydronuclear safety tests will violate the spirit (and maybe the letter) of a CTB. Again, it was emphasized that a stockpile stewardship program must be couched in a unified package of goals and facilities—laundry lists will be roundly rejected.

Beyond the "stewardship" debate, there was an underlying recognition that the labs will have to move into heretofore nontraditional nuclear roles. Even though warhead development, testing, and production will cease, the importance of nuclear weapons will not. The labs continue to be the chief repository of nuclear knowledge; knowledge which gives them first bidding rights in developing technologies to:

- Support U.S. and international nonproliferation goals, mainly by monitoring potential proliferators;
- Help verify and support a CTB;
- Implement the START I and II agreements, and facilitate the weapons reductions imposed by these treaties, especially in surplus plutonium disposition.

Other points raised in the discussion included the issue of security classification, budgets and alternative missions. To what extent will the labs continue to be involved in secret work? The collective opinion was that the labs will always have some classified work to do as long as they're working with nuclear explosives, but the percentage of classified tasks in their overall mission will probably decrease.

How much money will the labs need for the "stewardship" mission? There were no concrete answers forthcoming, perhaps because the role itself is only vaguely understood, at least by Congress, which pays the bills. One pragmatic voice suggested that the money needed is the amount that Congress is willing to appropriate.

Glancing even further ahead, a few speculated that the labs might be dedicated to pursuing long-term technological goals in the interest of society, e.g., securing a viable energy source for the future.

III. Constraints

Hanging over the discussion was the lugubrious realization that financial cuts are coming thick and furious already at the labs, and will only continue. On the one hand, they won't be able to test new or even old warhead designs; on the other, they are being asked to maintain a "rebuild capability." The response to this ranged from glum to depressive. In the view of the participants from the labs, they are currently in free fall—in terms of budgets and scientific competence alike—and, on looking down they see "nothing but clouds!"

Like every other federal agency, the labs are being subjected to a forced belt-tightening. Generous bonuses are encouraging early retirements, funds are being slashed, discontent is mounting. Uncertainty reigns supreme. But more than that, some participants clearly felt that the national nuclear weapons labs are being cast—along with the Cold War—onto the dust heap of history. Some advanced the argument that this sort of feckless chopping is bound to detract from our nation's ability to manage our nuclear weapons—a loss that we can ill afford. Others responded that the gravy eighties are over, and the labs will have to do more with less. Maybe one weapons lab and part-time consultants can do the work of two full-time labs; consolidation and integration are today's rallying cries. This was meager consolation to many participants, many of whom seemed to have a worried ear cocked towards a distant Congress, whetting its knife.

PANEL II: PLANNING FOR CONVERSION

The Original Conversion: Making the Future at the Applied Physics Laboratory after World War II

Michael Dennis

IMMUNE FROM THE PAST?

The cold war is over. Whether it was the *Wall Street Journal* headline, "With Cold War Over, Los Alamos Seeks New Way of Doing Business"; the *Washington Post*'s explanation of Martin Marietta's new goals for the Sandia Laboratories; the coverage given to the new administrations's first defense budget; or the recent cover of *Fortune* extolling the virtues of reengineering the corporation, the problems posed by the end of the cold war have become an unavoidable aspect of contemporary politics.[1] The argument in any of these pieces, and countless others like them, is really quite simple—the sudden collapse of the Soviet Union has left the United States with an industrial, technological, political, and economic infrastructure dedicated to fighting an enemy which no longer exists. America must now turn the resources devoted to waging cold war towards the development and improvement of the U.S. economy so that the nation might prosper in the new global marketplace. Competitiveness replaces national security as the goal towards which government action is directed.

Several related arguments follow from discussions of the cold war's conclusion. For our purposes, the most obvious relate to claims about the character of post-World War II research and development, in particular, the belief that massive military patronage produced a corps of researchers unable to work within the constraints of the marketplace and that products destined for the battlefield find little use at home. Within this framework, a significant problem emerges: how do we harness institutions used to develop weapons and other advanced military technologies to generate the sophisticated and profitable technologies of the future? The development of

[1] Scott McCartney, "With Cold War Over, Los Alamos Seeks New Way of Doing Business," *Wall Street Journal* 15 July 1993; Ross Kerber, "Martin Marietta to Run DOE's Sandia Laboratories," *The Washington Post* 27 July 1993; and Thomas Stewart, "Reengineering: The Hot New Managing Tool," *Fortune* (23 August 1993).

the CRADA, the cooperative research and development agreement, at each of the national laboratories, is certainly an attempt to link the laboratories to the marketplace through particular corporations.[2] In theory, the CRADA allows for the best of both worlds; one in which the laboratories continue their traditional research while also working with private firms to develop commercial products and processes. Furthermore, as an instrument of change, the CRADA satisfies at least two divergent constituencies. For those who believe in the laboratory's original mission, the CRADA does not pose an immediate threat to continuing that mission. For those demanding an abandonment of the nuclear and military programs and the conversion of the laboratories into engines of economic growth, the CRADA postulates a possible transition phase in which the laboratories gradually acquire a role in the commercial world. The CRADA, like any good bureaucratic invention, allows for patrons and contractors to measure each laboratory's involvement in the non-classified marketplace, although simply counting the number of such agreements and their results is a crude and ultimately misleading metric. Finally, using the CRADA is most likely an inherently conservative strategy, that is, it is a strategy to deal with external change while preserving the laboratories as significant national resources.

The CRADA may be a useful instrument of contemporary technology policy, but it seems somewhat anemic given the scope of the problem confronting not only the national laboratories, but much of the federal, and in particular, the military research and development effort. If we stand at a pivotal historical moment, one precipitated by the dissolution of our enemy, do we not have an opportunity to rethink the basis of our research and development program? That is, must we simply innovate around the edges of the problem, or might we attempt a more radical transformation, one that comes under the rubric of conversion? At a recent meeting at Los Alamos, one of the senior researchers, Paul White, made a remarkable statement. He explained that

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[2] For information on the CRADA, see Lewis M. Branscomb, *Empowering Technology: Implementing a U.S. Strategy* (Cambridge: MIT Press, 1993); and "Taking on the Future," *Los Alamos Science* 21 (1993) 4-30.

> at this moment, the Laboratory has a unique opportunity to define its future, one that will be more closely tied to the economic security of the nation.[3]

White clearly appreciates the possibilities presented by current circumstances, but that recognition is curiously circumscribed by a sense of what is genuinely feasible. Possible institutional revolution is supplanted by the more gradual process of institutional reformation. Without favoring either alternative, why not explore the former since we already have experience with the latter? In particular, why not ask the question whose very answer undergirds the existence of the national laboratories, and most of our national research and development: what is the appropriate relationship between the armed services and the producers of technical knowledge? Addressing this question also allow us to make use of the past, especially the debates at the end of World War II which produced much of the current institutional framework.

During World War II, a consensus emerged concerning the need to harness science and technology for national defense; what did not emerge by the end of the war was a consensus on how to organize such research.[4] The absence of a general solution produced a crisis in many laboratories created for the war effort as each confronted the distinct possibility of their imminent dissolution. In some labs, like the MIT Radiation Laboratory, the pre-eminent U.S. radar research center, laboratory liquidation and the staff's return to academic and corporate life was the designated solution to the war's end. At other wartime institutions, like Los Alamos, there does not seem to have been much of a debate over possible postwar futures; instead, strong actions by both Norris Bradbury, the lab's postwar director, and General Leslie Groves, head of the Manhattan Engineering District, made it clear that some type of laboratory would continue to exist.[5] At other laboratories, the problem of post-war survival was very real and demanded a solution acceptable to researchers, patrons, and university administrators. After all, a major mili-

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[3] See "Taking on the Future," *Los Alamos Science* 21 (1993) 16.

[4] On this point, see Michael Sherry, *Planning for the Next War* (New Haven: Yale University Press, 1977) 120-49.

[5] Bradbury describes these actions in "Los Alamos—The First 25 Years," in Lawrence Badash et al. (eds.), *Reminiscences of Los Alamos, 1943-1945* (Boston: D. Reidel, 1980) 161-75, 163, 165. I suspect that when the history of postwar Los Alamos is written up that these remarks will have to be revised.

tary or even federal presence on campus was unprecedented. Before World War II, the private philanthropies, especially the Rockefeller Foundation, were the dominant patrons of American science and the biomedical disciplines the financially favored areas of inquiry. The war eradicated that prewar political economy of science. Examining how researchers and others conceptualized post war defense research at an earlier, formative period might expand our own horizons in conceptualizing a future for the national labs. In particular, I want to use the history of the Johns Hopkins University Applied Physics Laboratory (APL) as my case study, for it offers an unusually rich mixture of possibilities. Furthermore, examining APL's history reveals how we need not rely on professional policy makers for ideas; at APL the researchers developed a set of possible futures, while negotiating with their Navy patrons and the university with which they were ostensibly affiliated. Finally, a caveat. It is tempting to suggest that APL's history is utterly irrelevant to an understanding of the national laboratories, since APL is not a national lab nor does it possess a nuclear mission.[6] I have two responses to such a criticism. First, distinguishing between a nuclear and non-nuclear mission may not be so crucial, since the argument over whether we should continue supporting the laboratories has more to do with the unique ensemble of skills which each laboratory possesses rather than the particular technologies under development at each lab. We should not let the technologies determine either our policy or our understanding of history. Second, we should see what APL's history provides us with before we dismiss it on a priori grounds. Policy, and politics, is better done within the framework of a known history than an abstract policy.

VOICES FROM THE PAST[7]

Established in March 1942, the Applied Physics Laboratory was originally part of Section T of the wartime Office of Scientific Research and Development (OSRD). Under the

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[6] But I can point out that the laboratory did play a role in the Manhattan Project; see Vincent Jones, *Manhattan, The Army and the Atomic Bomb* (Washington: U.S. Government Printing Office, 1985) 508.

[7] The following materials are part of a larger project examining the history of laboratories in the postwar American state. For references, please contact the author.

direction of physicist Merle Tuve, whose entire career had been with the Carnegie Institution of Washington's Department of Terrestrial Magnetism (DTM), Section T developed the radio-based proximity fuze, primarily for anti-aircraft shells. Using specially designed miniature vacuum tubes, the radio proximity fuze emitted radio waves during flight; when the reflected intensity of these same radio waves reached a pre-determined level, the fuze detonated the shell's explosive charge. Enemy aircraft triggered their own destruction. APL owed its existence to the immense technical and political problems involved in moving the fuze into mass production in late 1941 and early 1942. Technically, the problem confronting Tuve and his staff was among the most difficult faced by wartime researchers. By late 1941, Section T had managed to produce an exquisitely crafted handmade device capable of withstanding the massive accelerations in an artillery shell as well as the rigors of everyday military handling. Built by PhD physicists and engineers, assembled from meticulously inspected components and fitted together with great care, the fuzes were among the most sophisticated electronic devices of their time. Made in batches numbering in the hundreds, these devices "worked" in the laboratory and at the firing range. How was one to move this device, and the ensemble of skills which made its manufacture possible, into factories which would need to produce hundreds of thousands of fuzes with a work force quite different than the members of Section T?

In addition to this "technical" problem, there was a more profound political problem. According to Bush and the other leaders of the wartime research and development effort—Harvard president James B. Conant and MIT president Karl T. Compton—the OSRD operated in a social space bounded by the corporations that would build the weapons developed under OSRD contracts in both universities and other research organizations, and the armed services that would use the new technologies. Production was something contracted for by the military and done by industry; yet already Tuve and the leaders of the Navy Bureau of Ordnance (BuOrd) envisioned Section T playing a vital role in the production process. To engage in production was to break down the boundaries separating the academic researchers from their more powerful military and industrial partners, boundaries which were implicit in the very structure of the wartime research organization—the OSRD. For Bush and Conant, the design and development of the fuze was the province of academic researchers, but the production and use of equipment were matters for corporations and the armed services, respectively. For Tuve, "research and development" had "no value as an end in itself." Value only emerged from the actual use of the device; following the fuze into the factory and onto the battlefield was simply a matter of completing the job. Tuve and the Navy were ready to enter private factories and dictate orders to individual corporations, but the leaders of the OSRD were unprepared for such a move.

After much deliberation, and several attempts to force Tuve to conform, Bush and Conant gave Tuve his way. Their solution was a form of organizational quarantine in which the OSRD would establish a new institution, the APL, to deal with fuze production problems. As the new laboratory's director and head of Section T, Tuve would report to the OSRD director's office through Navy Commander W.S. Parsons. Section T was now organizationally separate from the remainder of the OSRD; the transfer of two million dollars from the Navy to the OSRD in support of the Section's new work made it clear that the new lab was more a ward of the Navy than the OSRD. The scale of the planned operation made current DTM accommodations inadequate. Isaiah Bowman, president of the Johns Hopkins University, agreed to administer the new laboratory's contract with the OSRD, even though APL was located far from the university's Baltimore campus. As for the nature of the relationship between the laboratory and the campus, Tuve explained that

> the Applied Physics Laboratory is in a Washington suburb, not at the University in Baltimore, and has no connection with the peace-time activities of the University, and has nothing whatever to do with students. This is a special research laboratory set up by the Office of Scientific Research and Development to handle an emergency Navy problem, and the President and Board of Trustees of Johns Hopkins University agreed to sponsor the laboratory and guarantee the proper handling of Government funds.

Due to the classified nature of the new laboratory's research, Bowman appointed one member of the university's board of trustees, David Luke Hopkins, a prominent Baltimore banker, to serve as the connection between the laboratory and the university administration. Luke Hopkins' signature was essential for spending any of the government's money; he also became one of Tuve's closest advisors, playing a major role in the debates that would shape the laboratory's future laboratory at war's end.

APL's staff of nearly two hundred individuals took over the management of the fuze's production, coordinating the activities of other laboratories engaged in further fuze developments as well as factory assembly lines. To control production, Tuve engaged in a two-pronged strategy. First, APL developed an extensive internal reporting system that kept the director informed about all aspects of research, development and production. Such a system furthered the laboratory's mission, but it also allowed Tuve to exercise authority over a staff in which only a few people actually knew the scale and scope of the project. That is, the program was so compartmentalized that Tuve needed to develop bureaucratic mechanisms to reconstruct the laboratory's technical practices. Security was not simply an additional layer of organization at APL, security was constitutive of the laboratory's workings. Second, Tuve dispatched the fuze's designers to assembly lines across the country. On the factory floor, the former DTM physicists—including Lawrence Hafstad, R.B. Roberts and others from universities and industry—attempted to recreate laboratory conditions at each worker's assembly line position. Those who knew how to build fuzes taught those who would mass produce the devices. Such a movement was necessary to transmit the skills necessary to build a working fuze. PhDs taught workers how to recognize flawed vacuum tubes, as well as the fuze's other components, while struggling to convey a sense of the delicate touch necessary to make a complete fuze.

To ensure that troops used the new technology, Tuve had several members of the staff accept Navy commissions. Once in uniform, these newly commissioned civilians spread the gospel of the fuze, patiently schooling other officers and sailors in the uses of the new weapon. As important as this missionary zeal was Tuve's deliberate overdesign of the fuze's safety features. APL proximity fuzes possessed multiple safety systems, ranging from a battery that did not arm the fuze until after firing, to special shock absorbing components to prevent accidental detonation during routine handling. For Tuve, such overdesign was essential if troops were going to use the new weapon. Were the new fuzes seen to trigger premature detonations or muzzle blasts, they would have simply gathered dust in the ship's magazines. Because of these efforts at distribution, as well as production, the fuze became one of the Allied wonder weapons, what one observer called "Atomic Bomb Jr."

Success exacted a price. In January 1943, Bush suggested that Section T join forces with Division 7 of the OSRD (Fire Control) to integrate radar, the new Navy Mark 14/15 gunsight, and the proximity fuze. Although fuze production was still somewhat problematic, Tuve and his staff believed that the period of greatest urgency had passed and were already discussing with their Navy patrons the changes a working proximity fuze demanded in anti-aircraft fire control. In addition to Tuve's desire to extend the reach of Section T/APL, the Joint Chiefs of Staff and the Navy Bureau of Ordnance (BuOrd) specifically asked Bush to keep Section T together rather than transfer workers to other defense projects. An intact Section T could solve whatever proximity fuze problems might appear as production and use of the fuze increased. Unfortunately, other parts of the OSRD did not share the military's affection for Section T/APL. In particular, the members of Division 7 refused to work with Tuve's group unless Section T's "anomalous" relationship to the OSRD ceased and "its status as a Naval agency [be] clearly recognized." Division 7 and Section T/APL pursued parallel paths, but never worked closely together. Instead, by November 1943, Bush tried to have the Navy BuOrd take Section T/APL off his hands; the Navy declined the invitation, but did meet Bush's demand to provide the OSRD with Section T/APL's entire budget for the coming year. Within a year, Bush would rid himself of Section T/APL and Division 7's wish would come true—Section T/APL would become part of the Navy.

Nineteen forty-four was a pivotal year in Section T/APL's history for three distinct, yet related reasons. First, during the summer, Tuve and his colleagues began work on an anti-aircraft, jet propelled guided missile, called Falcon. Second, Tuve served as one of the more vocal members of the Wilson Committee, charged with planning the organization of postwar military research and development. Third, in September 1944, Bush attempted to begin demobilizing the OSRD research effort, declaring that only research which might affect the outcome of the war against Japan be continued. By December 1944, missile research and postwar planning had produced a new institution. Deciding to examine the problem of supersonic antiaircraft missiles launched APL into a research effort that would last well into the foreseeable future. Acknowledging that "this whole thing looks like a big job," Tuve had "reluctantly concluded that we may have to face it during this war instead of the next one." Enemy aircraft attacking capital ships with guided missiles possessing a range greater than traditional anti-aircraft artillery would "deny" the U.S. "approach to any major land area." Although Tuve and his Navy patrons originally only wanted to study the problem, the APL group also believed that a solution was essential if the U.S. was to "hope for real defense against future air attacks in this shrinking world." By November, the Navy BuOrd believed that such a weapon was both "feasible and practicable" and capable of being "developed and produced" in time for "the present war."

Technology alone, even one as potentially powerful as a guided missile, could not create a stable future for the laboratory. As early as 1943, Tuve and his colleagues, especially David Luke Hopkins, had begun discussing ways to preserve relations between researchers and the military after the cessation of hostilities. Luke Hopkins and Charles Garland, another member of the Johns Hopkins Board of Trustees proposed an independent National Institute of Ordnance Research, which was embraced by the armed services. And, in June 1944, Secretary of the Navy James Forrestal appointed Tuve to serve on the Wilson Committee, charged with developing a mechanism to provide for the military's post-war research and development needs. As Daniel J. Kevles observed, Tuve dominated the early meetings of the Wilson Committee, presenting the assembled members with his plan for a new independent agency, a Research Board for National Security (RBNS).[8] The ultimate failure of the RBNS is well known, but there are several features of Tuve's vision that are important for our story. First, the idea of an independent agency had emerged from within Section T/APL at least one year before the convening of the Wilson Committee. Second, historians and contemporaries rightly made much of Tuve's emphasis on an independently funded agency, but Tuve did not believe the issue of funding was as important as the question of attitudes—the attitudes of the public, the Congress, the armed services, and researchers—towards military research and development. "Attitudes," explained Tuve, would "control the future opportunity and willingness to do this work, the quality of the ideas put into it, the initiative and vigor with which they are pushed, and even the funds which will be available for it." Only a change in attitudes could make researchers possess "any vitalizing sense of responsibility for the defense of this nation." Without such a sense, the nation would only repeat "the greatest error we have made as a nation of free citizens." National security could no longer be left to the military alone. Hence, when the committee's service members decided that the organization of research within the services was outside the committee's jurisdiction, Tuve argued that the committee had been "pretty thoroughly torpedoed." If attitudes were central, then the military's intransigence towards a discussion of its own research signalled that there

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[8] See Daniel J. Kevles, "Scientists, the Military and the Control of Postwar Defense Research: The Case of the Research Board for National Security, 1944-1946," *Technology and Culture* 16 (1975) 20-47.

was no forthcoming attitude change. We should note that the committee never accepted Tuve's scheme; instead, they endorsed a plan which made use of a RBNS located within the National Academy of Sciences. Ideally, the armed services would transfer funds to the Academy, which would then fund defense research. This plan collapsed for a variety of reasons, not the least of which was it constitutionality; that is, could an ostensibly private body, the Academy, receive and subsequently dispense public monies. Tuve would get another opportunity to engineer the military's attitudes—in particular, the Navy's—courtesy of Vannevar Bush.

In September 1944, Vannevar Bush announced that once the European war ended, the OSRD would begin demobilizing. Only those projects essential for prosecuting the Pacific conflict would continue, preferably under the sponsorship of the military services with an interest in such research. After much protest, Bush's demobilization scheme was only partially implemented, but not before Tuve had used the uncertainty created by the plan to Section T/APL's advantage. With Bush's blessings, Tuve and Luke Hopkins began negotiating a contract between the Navy BuOrd and Johns Hopkins to continue the work of Section T. For Tuve, the orderly transfer of APL from OSRD to Navy auspices might serve as a model for the transfer to the services of other projects of technical and strategic importance while eliminating some of the uncertainty among the laboratory's staff precipitated by Bush's demobilization plans. For Bush, the transfer rid the OSRD of an "unusual and undesirable" organization. In December 1944, Johns Hopkins formally accepted a $750,000 Navy contract to manage the laboratory for the BuOrd through June 1946. In January 1945, the APL became the Navy center for guided missile research, charged with the development of a working antiaircraft missile for use in the current conflict. War was the operative context for the transfer, but how would the laboratory manage without that context?

In late May 1945, Tuve dictated a memorandum entitled "Emergency Peace Status," with a remarkably prescient assumption: "If Japan <u>quits</u> in summer (or early autumn) 1945." This was a novel assumption for Tuve; in late April 1945 he estimated the war's end by July 1947, plus or minus one year. The prospect of an earlier conclusion would generate an "emergency," as well as the exclamation: "Wow! Nobody is ready for such a crash!" In the "chaos" of a sudden victory, would the Navy, Johns Hopkins, and the laboratory's staff have an opportunity to preserve "order," and design a future organization to continue the missile work, now called

Project Bumblebee? After considering the lab's staff requirements, even in the face of sudden peace, Tuve could claim, "We won't sink!" APL might not sink, but the blasts which ended the war caused the laboratory to take on water.

August 1945 brought forth Tuve's emergency scenario—a Japanese surrender. Tuve and the laboratory's senior staff had spent countless hours discussing the shape of postwar military research and development; in June an all night conversation yielded an "ideal structure for post-war research," but as in a dream the details faded in the light of day. For Tuve, any specific plans for the future of Section T/APL had to be guided by a more general set of beliefs over the proper relationships between military officers and civilian researchers. Outlined most forcefully in April 1945, the ideas embodied a conception I will call "technological citizenship." That is, the most important point which Tuve focused upon was the need to

> [m]ake civilians <u>realize</u> their obligations for defense and its vital importance, and give them the means for carrying out this obligation.

Conversely, it was equally important to "[m]ake the Navy part of the U.S.A." The goal was a continuous "pattern" of relationships binding the civil and military worlds, transforming each. Close relations would "insure" against obsolete technologies in the armed services, while forcing an "<u>informed</u> group of citizens" representing science and industry to possess "an interest in the international scene and an evaluation of the current <u>needs</u> for defense." External civilian re-searchers would help in assessing the service's research needs and provide solutions, while the officers would make the researcher's aware of the problems confronting the U.S. in the world. Only researchers working outside the military could make such a contribution. Reliance on researchers working within the services was inadequate to these ends for two different reasons. First, such workers were civil servants, where seniority triumphed over originality. Like so many others, Tuve believed that the civil service was inimical to original technical inquiry. Second, extended weapons research was something to do for part of one's career, rather than the work of a lifetime. Close integration of civilian and military activities would make such a career path possible. How to establish and maintain relationships among researchers, military officers, and businessmen became the central problem; its solution would have important consequences. National security was now the result of a reinvention of civil society, rather than a cause. In turn, Section T/APL, an "experiment in public service," became a wartime example of such close integration, exemplified by the contractual relation between Johns Hopkins and the BuOrd. Yet, the postwar existence of Section T/APL was not the only way in which Tuve's vision might survive at war's end. And others at the laboratory and the university would have their own ideas.

Two weeks after the war's sudden end, Tuve convened two committees composed of laboratory staff members to map out APL's future. Labelled the Young Turks and the Seniors, for their generational differences, the committees began their tasks with a common set of questions and assumptions. Each was to consider the potential needs of the U.S. with respect to research and development in light of possible future enemies, the possible BuOrd research and development activities, and the role Section T/APL as well as Bumblebee might play in their view of the nation's and the Navy's future. Among the common assumptions was the ability of the Navy to let contracts for more than one year, no real changes in the Civil Service, the existence of some RBNS or equivalent with an interest in nuclear physics, and the possibility of a transition period under Johns Hopkins sponsorship for a year or more.[9] Both groups returned with similar plans and both differed quite dramatically from Tuve's own conceptualization of the future. According to the Seniors, there was no need to change the wartime arrangements in the least; Johns Hopkins would remain the nominal sponsor, but with a continuation of the wartime contractual relationship. Should the university decide to end its sponsorship, then another sponsor would be found. For the Young Turks, the laboratory needed to continue so that the armed services would have access to "quantum jump" weapons (i.e, radar, atomic bombs, proximity fuzes, and guided missiles), devices whose very existence might change the course of a war. Rather than remain affiliated with Hopkins, the Young Turks proposed turning Section T/APL into a "privately-endowed military research institute" supported by direct service contracts, government grants, and patent revenues. The newly independent laboratory would continue work on Bumblebee while attempting to interest the other services and their monies in the new weapon. Both groups saw the laboratory's future as their future; war's end did not mean the laboratory need disband. War with the Soviet Union was another shared prediction; the Young Turks entitled their planning memo, "Post (Pre?) War Planning." The importance of the weapon under development for

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[9] See 18 August 1945, Tuve to Committee Members, MATP Box 114, "Tuve Administrative Files APL, September 1945."

the coming conflict, as well as the laboratory's wartime track record, would insure the future, despite the recognized lack of any precedent for such an organization. Such faith in the laboratory's future stood in stark contrast to Tuve's own apparent belief that the laboratory would "disintegrate" as people returned to their pre-war pursuits, leaving APL a hollow shell of its wartime self.

Confronted with his staff's belief in the laboratory's postwar necessity, Tuve attempted to craft a compromise plan which might meet with the approval of his staff and the Johns Hopkins administration. The latter requirement was one of Tuve's serious disagreements with his staff; Tuve, unlike the Young Turks or the Seniors, did not understand how the laboratory might survive without a substantive university connection. In turn, the university affiliation demanded that the postwar laboratory differ dramatically from the wartime organization. Control of the Section T/APL contractors would diminish and a loose confederation of contractors, both academic and industrial, would emerge, guided by the postwar APL. This arrangement would "differ very materially" from the wartime APL; no longer would APL perform the over-all synthesis. "We are," explained Tuve, "endeavoring to preserve not a Johns Hopkins laboratory, but an over-all pattern of technical operations with a wide base, spread over a variety of agencies and groups in the nation." A single statement crystallized the gulf separating Tuve from his staff, but it also captured some of the differences that would distinguish Tuve's reasoning from that of Hopkins president Isaiah Bowman.

To assist in the retention of personnel for Bumblebee, Johns Hopkins acceded to a Navy request to extend the university's contract an additional year, until June 1947. Relations between the laboratory and the university remained unspecified, although Tuve attempted to implement his own plan in October, explaining to the staff that all changes were part of an "evolution toward a valid and effective postwar pattern." In other words, the laboratory's future form remained undecided, at both APL and Johns Hopkins. For Luke Hopkins, the prosecution of guided missile research was essential for the nation's future security, but the organization of such work was not obvious. For Bowman, Johns Hopkins was participating in an experiment to determine the effect of APL's research upon the university, but he disagreed with Tuve and Luke Hopkins on the character of the connections between the laboratory and the campus. Tuve and Luke Hopkins argued for the <u>integration</u> of the two, but Bowman believed that <u>cooperation</u>

described the appropriate relationship. Bowman and the university's trustees wanted to preserve APL as the nucleus for a long-planned industrial research contract laboratory; the technical skills of the APL staff would turn towards ventures more commercial than guided missiles. Even more important, affixing APL to the new industrial contract laboratory, obviated the need to provide APL staff members with university appointments. That is, Bowman and others on campus feared a sudden influx of APL researchers possessing tenure should the Navy abruptly cancel the laboratory's contract. The unexpected transfer of APL employees to the university payroll would be disastrous, but it was the sudden move of individuals that departments had not selected which disturbed Bowman and department chairmen. Cooperation promised benefits with few visible costs. In turn, a university connection allowed Bowman to define the category of activities "appropriate" to the university. With this resource, Bowman demanded a significant change from the laboratory—the separation of research and development from prototype and production engineering. An industrial concern would be found to handle the later tasks. Such a division undermined APL's wartime history of "only dirty hands can intelligently direct," but such a division was the price Bowman placed on continuing university sponsorship as well as a demonstration of Bowman's belief that he and the Trustees would decide the university's future status.

"Great" confusion still reigned at APL and Johns Hopkins in December. The Young Turks and the Seniors, including Tuve's prewar DTM colleagues, R.B. Roberts and Lawrence Hafstad, collaborated on the production of a prospectus for the "Section T Research Laboratories," an attempt to demonstrate that the laboratory could become a privately endowed not-for-profit laboratory; the prospectus was an explicit rebuke to plans for attaching the laboratory to Johns Hopkins on a permanent basis, especially if the price of affiliation was the loss of a role in production. On 12 December, Luke Hopkins announced that a potential collaborator to perform the laboratory's production functions had been found, the Kellex subsidiary of the Kellogg Company, famous for its role in the Manhattan Project. After Hopkins' presentation, the staff asked if the university might not reconsider and allow the laboratory to continue as it had during the war. In particular, why not allow the laboratory to operate as a separate, but equal part of the university, similar to the hospitals in East Baltimore? Luke Hopkins emphatically denied such an option. Unless an "angel" were to appear, with the resources to either capitalize the prospectus' private lab or absorb Section T/APL in its entirety, the future lay in a collaboration with

Kellex. What kept the laboratory together was the widespread belief that APL was the best equipped group to solve major problems for the military and industry, as well as the staff's refusal to abandon their two most significant technological innovations, Bumblebee and the laboratory.

University administrators, as well as the laboratory's staff, found the Kellex proposal tolerable, but Tuve believed the scheme profoundly flawed for several reasons. First, Johns Hopkins had not offered professorships with tenure in the academic departments to any member of the senior staff. Nor had Bowman even stated how many offers might be made in the immediate future. Hence, the university wanted only a contractual relationship with the off-campus laboratory, rather than a substantive connection which would transform both institutions over time. Second, since Tuve agreed that the university should not participate in the production engineering of specific missiles, he did not see why the staff continued to believe that a large central laboratory remained essential. Surely, a staff of fewer than one hundred people would suffice. Finally, Tuve was quite hesitant to bring in an industrial contractor to sever the laboratory from its manufacturing duties, especially since Kellex and Johns Hopkins would share responsibility for the laboratory. Why not allow Kellex to contract directly with the Navy instead of through the university; why hand

> over to an aggressive group, new to BuOrd and to GM [guided missile] work a central-lab-plus-contract-control system for which the sky is the limit.

Kellex's future profits were of no concern to Tuve; nor was he sure that Kellex was the best choice to share responsibility for the laboratory with the university—others firms figured in his thoughts. Despite his misgivings, Tuve assisted in negotiating the division of responsibilities between Hopkins and Kellex. Hopkins would retain control of the "broad planning" of Bumblebee as well as "broad scientific or technical research programs," necessary for missile development; Kellex would bear responsibility for the development of specific missiles. In Tuve's scheme, Kellex did the work of designing and engineering particular weapons for production, while APL bore responsibility for the ideas and concepts embodied in specific missiles.

Turmoil continued at the laboratory as Tuve's frustrations mounted. The staff, led by Lawrence Hafstad, R.B. Roberts, and Wilbur Goss, still wanted to continue with the wartime laboratory, causing an exasperated Tuve to declare, "Christ! The war's over!" In a draft letter of resignation, Tuve explained to Luke Hopkins that

> a general hope has been sustained that this APL laboratory might continue on more or less of a large-scale wartime basis over a period of years. The entire situation here is now unrealistic to a point of absurdity.

What was now a crucial problem was the utter lack of involvement by the university in the laboratory's daily operations; Tuve, Hafstad, and Roberts, three of the laboratory's leaders were on leave of absence from the DTM. Luke Hopkins, an administrator, not a researcher, was the only person from the Baltimore campus among the 700 people still employed at the Silver Spring laboratory. In Tuve's eyes, neither the university nor the staff were being realistic; rather than allow his continued presence to condone the possibility of continuing the wartime pattern, Tuve tendered his resignation, effective by 15 February 1946. Tuve could not completely sever his relationship to the laboratory; he would remain a consultant, directing his attention to the

> evolution of a realistic and acceptable philosophy regarding various aspects, especially the constructive aspects, of the future defense of free citizenship.

What Tuve had not counted on was that his own rather radical revision of the civil-military relationship might not interest either his own staff or the university administration, both of whom had quite different objectives which would come into conflict with his resignation.

With Tuve's departure, Lawrence Hafstad became director, while Luke Hopkins retained his position as the link between the laboratory and the university administration. The problems which now appeared, and would not disappear, were the question of the laboratory's relationship to the university and the division of responsibilities with the Kellex Corporation. The former problem was now old, but still unsolved. Bowman and Luke Hopkins believed that the creation of a new division of the university, the Institute for Cooperative Research (ICR), would solve the problem. APL would become the largest part of the new division and staff members would receive academic appointments in the ICR rather than the traditional academic departments. For the university, these appointments allowed the APL staff to have academic titles, while freeing the academic departments from the burden of absorbing staff members should the laboratory contract end abruptly. Far from providing APL researchers with the benefits of academic life (i.e., tenure), these appointments allowed the university to insulate itself from the laboratory.

Plans for a new aeronautics department clearly demonstrated the university's desire to profit from its association with the laboratory; the university hoped to attract top level researchers and additional contracts with the laboratory's resources. Yet, other than an affiliation with a new university division which existed only on paper, it was unclear what the laboratory would receive. Ironically, although the staff had disagreed with Tuve, several apparently believed that a continuing university connection would bring a traditional academic position and integration with the Baltimore campus. Ralph Gibson, one of the senior staff, wanted a title in the form "X—Professor of Y in the Johns Hopkins University and not in the I.C.R./APL." And James Van Allen, one of the young Turks, found the ICR-APL arrangement suitable "until we have an opportunity to get a personal impression as to how real the integration into JHU appears after a year or two." Bowman emphatically denied that the ICR was an "imagined unit," but this was a problem whose solution would prove dramatic.

Despite these political problems, work continued on Bumblebee. An outside evaluation committee commended the laboratory for the speed with which results had been obtained and expressed no reservations over the program's technical direction. The committee did ask what was the appropriate relationship between a university laboratory and weapons development in peacetime, but allowed for different answers at different institutions. APL researchers joined in the discussion, producing memos addressing the question, "What is APL?" and the nature of the JHU-Kellex relationship at the laboratory. Alexander Kossiakoff, one of the more outspoken members of the staff, declared that APL was a unique "collection of individuals," as well as a "complete operational team." For the laboratory to "grow roots," it would have to become permanent and acquire a "reputation for scientific achievement." Equally important, the laboratory would have to "retain full control of [Bumblebee's] engineering design and performance specifications." Kossiakoff's discussion of APL made clear the uncertainty felt by the staff while revealing an inability to conceptualize a role for Kellex in the laboratory's daily operations.

If institutional permanence was a problem, any proposed solution had to recognize the problems of location, classification, and patronage. Located in suburban Washington, DC, the laboratory was quite a drive from the university's campus. The establishment of a laboratory newsletter, filled with information about the staff and university could not, in and of itself, ameliorate this problem. If education remained an important part of the university's mission, how did the laboratory fit in? Bumblebee was a classified research program, where results were the immediate goal. How would students fit into such an effort? Despite plans to import graduate students from Harvard, there appears to have been little effort to develop a graduate program in guided missile design that might tap the laboratory's talents. Instead, the laboratory embarked on two pedagogical projects, directed towards practitioners rather than students. APL started producing a series of handbooks on supersonic aerodynamics. With articles written by leading experts in the field, including members of the staff, the handbooks were a way to control the flood of information emerging in this rapidly growing field, while placing the laboratory at the center. In a related initiative, begun in 1947, the laboratory established the Solid Rocket Propellant Information Center, a clearing house for information about the topic for government contractors. Both the handbooks and the information center were efforts in public relations, as was the only research program at APL which attracted any outside academic interest—James Van Allen's use of captured German V-2 rockets for cosmic ray investigations and solar spectroscopy. As Lawrence Hafstad explained to President Bowman,

> this is frankly intended to be one of the Navy's contributions to pioneering physics, without regard to practical end-results. However, we are keeping our eye on the matter of very energetic particles, carrying energies much greater than those involved in the fission of uranium.

Hafstad, then director, failed to mention another, indispensable part of Van Allen's assignment: the design of a liquid-fueled rocket capable of reaching high altitudes. Although designed for high altitude research, the Bureau of Ordnance seriously considered using Van Allen's rocket as a tactical weapon. Although Van Allen cooperated with the Hopkins' physics department and even taught several courses, department members refused to consider granting him a permanent appointment.

Van Allen's V-2 research worked as public relations both in and out of the laboratory. Outside the lab, the photos taken of the earth from unprecedented altitudes established APL as a leading scientific research institution. Inside the laboratory, the work demonstrated that despite the classified nature of the laboratory's major research project, there was a role for APL in the disciplinary economy of knowledge. Van Allen's work took place in the newly designated Research Center, a part of the laboratory set aside for unclassified or basic research, but such work was basic to military, rather than researcher, goals. It was indicative of the status of such research that Van Allen's group was nicknamed the "five-percenters," a reference to their portion of the APL budget. "Basic" research, like Van Allen's, also highlighted the laboratory's other problem—sole source patronage. If one could only use five percent of the budget from the BuOrd for such work, then why not get other contracts, from the other services and industry, to broaden the base of support? Kossiakoff and others mentioned just such a possibility, but they all realized the main problem—should the BuOrd believe that APL was diluting its efforts on Bumblebee in pursuit of other service or industrial contracts, than it was quite likely that the Bureau would shop elsewhere for its technological developments. Freedom from the Navy might bring the laboratory's history to an end. In turn, how would corporations feel about working with a laboratory that was jointly operated by a university and an industrial firm, Kellex, which might become a future competitor? Throughout 1947, these problems only deepened; as Gibson explained in late 1947, "closer attachment to the university by any reasonable means," was desperately needed. Ironically, Gibson himself would help spark the conflagration from which a final solution would emerge.

In October 1947, Lawrence Hafstad left the directorship of APL to become the executive secretary of the Joint Research and Development Board; Gibson, who was in charge of both the associated Section T contractors and day-to-day Bumblebee development, became the laboratory's acting director. At nearly the same time, Gibson began negotiating with Rutgers for a position that would allow him "to forge a better link between our research and development activities that give birth to new ideas with the engineering activities whereby these ideas are place at the disposal of the nation and the world." By early 1948, the Navy was "anxious to get some guided missiles on ships"; even if that meant deploying experimental prototypes. The conjunction of these disparate, and seemingly disconnected events produced a profound crisis at the laboratory, one that exposed the unresolved problems of the laboratory's connection to the university as well as the very basis for the collaboration with Kellex. The later had been the subject of numerous documents attempting to explicate the "philosophy" of the JHU-Kellex collaboration, but these generated more heat than light; there was no way to challenge the existing contract between the university and Kellex, since the relationship's most problematic component, the distinctions between research and development and production engineering existed as definitions in a contract rather than as part of organizational practice. All this changed with the Navy's new interest in making the weapon operational in short order. In early spring, Gibson received an offer from Rutgers, and the laboratory's "scientific staff" feared for the laboratory's future; just as they feared for their future as Bumblebee moved into the engineering and production phase of development. Under the terms of the original agreement, such a transfer implied that Kellex would soon take over the missile's future development. How the transfer would work remained unclear, but such a transfer was the reason for the Kellex collaboration.

If nothing happened, then both Gibson and the missile would soon leave the laboratory; the crisis produced a flurry of memoranda and meetings. In a joint declaration, twenty-five of the thirty-three senior staff members, explained that the current crisis was the upshot of running a laboratory "by a partnership with overlapping responsibilities." APL's responsibilities to the Navy could not be shared with Kellex for only the university and the researchers possessed the skills to bring the project to a successful completion. Despite all the efforts to make the joint operation work, divorce was the only effective answer. Kellex had to go. In response, the Kellex managers blamed all the problems on a "small (30) self-elected, non-representative group of competent scientists," who wanted to "dictate not only policy and direction of the Laboratory's efforts, but, in addition the detailed procedure and time scale which should be adopted." In particular, the choice of Gibson, a soft-spoken physical chemist with a fondness for poetry and the classics, as acting director had been a mistake, providing the "competent" scientists with a rallying point and leader. As the agreement unraveled, the Navy explained that the BuOrd had been "skeptical at the outset" of the joint operation and only went along to appease the university. However, in a more remarkable statement, the official Navy representative expressed his belief that one of Gibson's staff had been disloyal towards the acting director. It was a sign of how successful Gibson had been in convincing the Navy that he was the appropriate leader for the laboratory, while also steering the university towards the appropriate course of action.

The upshot was the separation of Kellex and APL, with Gibson remaining as director, but more importantly, the dismissal of Kellex meant that the laboratory would regain responsibility for continuing Bumblebee development as well as a role in production engineering. The latter was especially important since it not only allowed for a return to wartime practices, but it allowed for the researchers to (re)gain control of the missile development program from design through production. APL reverted to its wartime status in both name and function, but with an important difference: in 1948 Bowman made APL a division of the University, equal to the Medical School, the Undergraduate College, and the Graduate School. Gibson had done what Tuve found impossible; he had created at place for APL on campus, by emphasizing the very functions Tuve sought to drop from APL's mission.

Gibson also replaced Tuve's ideas of technological citizenship with an alternative philosophy—systems management. When, in 1957, the *Wall Street Journal* hailed Ramo-Woolridge for its "unique" supervisory role in the production of Air Force bombers and missiles, Gibson dashed off a letter to the editor stating APL's priority in the development of the new managerial strategy. For Tuve, technological citizenship was a vision of a radically different form of civil society; for Gibson, systems management or systems analysis, was an apologetic which legitimized APL's position in the weapons development and production process. Arguing that the entire research, development, and production process was a complex and interconnected system allowed APL to justify its dominant position. APL was all that stood between a working weapon for the Navy and chaos. This was also another dimension of the postwar conversion; university-based researchers appeared and acted like industrial contractors as well as academics.

Lessons from the Past

So what? What do we learn from this excursion into the past? One lesson is rather obvious—a truly radical break with the past was simply dismissed by nearly all the participants in our story, save for Merle Tuve. On the Wilson Committee and at APL, Tuve was in the minority. The radical remaking of civil society with the closer integration of the civil and military spheres was a lost cause. Instead, plans which diverged very little from the then current situation prevailed. No doubt, one reason for this was simply institutional inertia and a desire to stay with comfortable organizational forms, especially if one believed that war with the Soviet Union was only a few years away. Tuve took a rather different approach; he did not want to tinker with the laboratory's patronage; he wanted a wholesale reengineering of society.

APL's planning invoked an interesting and little appreciated insight—generational difference. Why have two committees—the Young Turks and the Seniors? In retrospect the reasoning is quite clear. The Young Turks had come of age during the war; most, if not all of their professional lives had been spent in the laboratory imbibing the elixir of unprecedented power and authority. The Seniors had experienced the crushing poverty of the depression and survived the job market's intense selection pressures during the thirties. They knew, as we also know, what it meant for every PhD to apply for the single job in a particular field. Tuve had clearly hoped that the Senior's experience would temper their report; he was crushed when both committees reached similar conclusions. A common recognition of the immense changes wrought by the war produced that disappointing similarity; forty-five years later we have an important problem with respect to generational differences. Who are our Seniors and Young Turks? Are the Seniors the surviving members of the Los Alamos generation who remember physics during the depression? Or are the Seniors the members of the generation that invented arms control as an academic experience and served as advisors to government? Also, who are the new Young Turks? Who has not come of age during the cold war and the support of the physical sciences by the military? Could it be that our common cold war experience has eviscerated our collective political imaginations?

If we have no immediate solution to the problems raised by Tuve's invocation of generational differences as part of his planning strategy, there is another point we should keep in mind. APL's future was determined, in large part, by the actions of the researchers, not by policy makers in Washington talking to academics and talking heads in think tanks. Researchers in the national laboratories have to either seize control of existing planning processes or create such processes, but whatever happens they must participate in the production of their futures. Paul White is right: the laboratories do have an unprecedented opportunity.

If we look at the options considered at APL, one of the most interesting was the attempt to make APL a private research institution. In 1946, those plans floundered because the researchers were unable to effectively capitalize the new laboratory. Capital markets have changed a great deal since 1946; government-backed bonds and patents, the two sources of revenue discussed in the original prospectus, are now only two among a vast array of financial instruments. I would like to know if there has been any discussion of making the national laboratories private corporations using all the techniques now available to the venture capitalist. Currently, the baby-boomers are desperately seeking higher rates of return for their retirements; this is only one cause of current market conditions, but it was unthinkable in 1946. Is it possible to use some of this capital to finance the privatization of the labs? We should note that this does beg the question of what is the proper mission of the laboratories in the post cold war era.

Finally, my discussion in this paper has drawn almost entirely upon the history of APL, but it should point out that each national laboratory's history is important, if only as a source of possible futures. That is, we might recover lost options if we are willing to read the memos which fill filing cabinets at Los Alamos, Livermore and Sandia. Part of the problem lies in the nature of each laboratory's work. Writing to his friend Maria Goeppert Mayer about a recent experience, Edward Teller explained

> [w]hat I want to tell you as best I can is something you will never see: An island without any women on it. A whole atoll without any women on it. In fact, the nearest woman was 300 miles away.[10]

There is much to say about this statement, especially with respect to current debates about technology and gender, but I quote it to make a very simple point. The research at the national laboratories has largely been work which the public has never seen. The laboratories are islands in the vast archipelago of postwar research institutions. Immigration is restricted and visitors require a special passport and visa. This invisibility demands that those who speak for the laboratories possess very special skills, since they must represent a world that most of us will never see. Ironically, unless the researchers take their future into their own hands, they too may never see that world.

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[10] See the undated letter in UCSD Archives, MSS 20, Maria Goeppert Mayer Papers, Box 3, File: "Edward Teller, Primarily No date." Given other textual clues, I suspect that this dates from the Mike 1 test; also, women were present at Bikini and other atomic tests.

PANEL II: PLANNING FOR CONVERSION

Chair: Susan Christopherson (Cornell)

Background Paper: Michael Dennis, "The Original Conversion: Making the Future at the Applied Physics Laboratory after World War II"

Panel: Maurice Katz, Department of Energy
C. Paul Robinson, Sandia National Laboratory
William Weida, Colorado College

PANEL PRESENTATIONS

Maurice Katz discussed the process underway in the Department of Energy (DOE) to examine the missions for the DOE laboratory complex. The laboratory missions include: enhancing understanding of energy production and use; advancing nuclear science and technology for national security purposes; assisting with the dismantlement of nuclear weapons and working to curb nuclear proliferation, including research on verification technologies; fundamental research in energy-related science and technology; hazardous waste management; work on technologies to help protect the environment; technology transfer activities with industry, academic, and State and local government; and contributing to the quality of science, mathematics and engineering education.

Each of the three weapons laboratories has been assigned specific areas of competence in weapons production to be maintained in case of future need. Where appropriate this may include taking back and preserving capabilities that had been placed in the contractor base. At the same time, DOE understands the importance of the new missions, such as technology transfer and conversion, for enhancing US economic security.

Paul Robinson pointed out that the laboratories had previously demonstrated their ability to respond to new missions, when they shifted into energy research in the 1970s, a shift that was largely reversed in the 1980s. The current workload for the laboratories as a group is split between nuclear weapons research, development and testing (50%), treaty verification and nonproliferation work (25%), and energy technologies, basic science and applications for the private sector (25%); at Sandia non-nuclear programs are roughly 50 percent of the total. There is still interesting work to be done on applying leading edge technology to increase the safety of nuclear weapons.

He mentioned some current projects at the labs, including work in advanced batteries, environmentally conscious manufacturing processes, and laser energy. Conversion projects are being carried out under five different programs: cooperative research and development agreements (CRADAs); sharing lab facilities with commercial users; national industrial challenges such as the recent auto agreement; technical assistance to small and medium sized businesses; and sharing lab technology with private venture startup companies. He noted that one of the comprehensive missions in the future could be nuclear stockpile stewardship—safeguarding, securing and dismantling existing weapons in the U.S. and in the former Soviet Union.

Bill Weida took a more skeptical view of the possibility of conversion at the laboratories so long as the old guard associated with the weapons program remains in control. For decades the nuclear mission drove the enterprise, and it is not clear what can replace it. Structural changes in the laboratories as a result of the changing mission have left whole groups without a mission. A mission in basic research provides a rationale for continued government funding, but would tie the labs to falling budgets.

Sigfried Hecker, the lab director at Los Alamos, has called for the labs to produce things of value with a business-like approach that respects the environment and to treat people with fairness and dignity. Weida argued, however, that the federal government had proven itself incapable of adequately determining value, a task Weida believed was best left to the market. He questioned the competence of the DOE and University of California to manage a commercially-oriented enterprise. If, on the other hand, the new big projects, i.e., the "flywheels," are to be in non-competitive markets, then "you enter the realm of politics where there is but one single advantage: weapons work." He accused the labs of "mission groping" in light of limited budgets and stated that spin-offs alone cannot justify the existence of the labs.

SUMMARY OF DISCUSSION (Rachel Weber)

The discussion focused on the question of new missions that could replace the nuclear mission as the "flywheel" for the national labs. Which new missions or product areas might offer the same guarantee of federal commitment, public resources and long lead times as producing weapons systems did? As part of this discussion Hans Bethe made a set of specific suggestions for arriving at new missions for the nuclear laboratories, which has since been published as an op-ed piece in the *New York Times*. A slightly longer version of Bethe's essay is printed as Appendix A to this report.

The presentations and ensuing discussion made it clear that new national focusing devices are needed to enable the labs to move smoothly into new areas of civilian technologies with minimum costs to their employees, to taxpayers and to the federal government. Questions were raised about who should determine and initiate the new missions, given the labs' inexperience in technology transfer and commercialization.

I. The potential for new "flywheels"

Suggestions for flywheel programs included civilian engineering and alternative energy production, responsibility for risk/technical assessment of new technologies, and additional research into AIDS or global warming. From one point of view the new missions are actually old ones, that is, a commitment to excellence in basic science research. The Manhattan Project showed that a huge outlay of funding will make things happen, but also that it is necessary to have a solid science base.

Whereas some felt that the labs should choose only those new missions that they can perform efficiently and not take on new tasks just to create busy work for the 1500-plus PhDs employed by the labs, others argued that the national labs should be focusing on exactly those areas of market failure where there are public goods at stake, but no good measure of efficiency. It was pointed out that technology transfer does not qualify as a flywheel; what is needed is a "regenerative" device so that there will be new technology to transfer.

II. Who will develop the flywheel and in what manner will it be implemented?

If there is to be a new focus of public investment, we will need a new leadership and new federal mandates for such flywheels. Left to their own profit-maximizing ways, private industry will not develop the type of national mission needed to revitalize the economy. In this vein, suggestions to privatize the labs were vehemently opposed. The public sector is best equipped to deal with cases of market failure, and the charter for the labs has already been made by public authorities, who will continue to determine missions. Without such federal oversight and subsidies, firms, universities and labs would be drawn into a competitive relations with each other.

In contrast, at least one participant believed that the researchers themselves should decide the future of the labs. As described in Michael Dennis's background paper, researchers in the past were able to create their own missions and subsequently market them to the military. If a flywheel is implemented in a top-down manner, the disjuncture between policy and science would ossify. Others agreed that labs need to be involved in these decisions and pointed out that Maurice Katz's presentation had a top-down flavor to it. The question is, Is the government currently bringing the researchers into the process or are they consulted simply as protocol?

Some of the participants from the laboratories felt that Energy Secretary Hazel O'Leary was actively soliciting the involvement of the laboratories and their researchers. The DOE is currently working with the National Institute for Standards and Technology (NIST), the Environmental Protection Agency (EPA), government working groups and committees to institutionalize avenues of participation. Historically, the labs have had some leeway in directing their own internal affairs because 25-30 percent of their funds were given to them to use at their own discretion; today, however, discretionary funds are limited by statute to 6 percent of the laboratory budgets.

Other laboratory participants disagreed with this optimistic picture. There are bureaucratic costs of dealing with DOE. Despite formal avenues for consultation, Congress and the Department of Energy speak a different language than the labs. This problem of miscommunication implies that the labs are not heard by a leadership with "wax in their ears." Some complained about feeling isolated from federal authorities, and claimed that staffers on the Hill know little about technical issues.

III. Should the federal government be subsidizing private industry, the national labs or both?

As the topic changes from national security to economic competitiveness, we need to question the value of indirectly subsidizing private industry through CRADAs and other technology transfer initiatives. Some felt that the labs should be funded to take on long-term research in civilian technologies. Others believed that the labs are not capable of taking on this responsibility. "Just because we invest so much in the labs, it does not mean that they are inherently valuable." It was also noted that technology transfer from the labs does not create local jobs and thus does not address the problems the local communities face from the defense drawdown.

CRADAs are an important component of the technology transfer process. Currently, Sandia can only find funds to work with one-tenth of the proposals they receive. The point was made that if CRADAs do not succeed, no one will care. However, if one succeeds there will be howls of uproar from private industry, that is, from the firms left out of the agreement, as exemplified in the Cray Computer case. Thus, the federal government needs to funnel funds into projects that are based in consortia like SEMATECH and the clean car projects in California.

Finally, we discussed the tension between serving the goal of enhancing national competitiveness through technology transfer and the reality that many of the technology programs have an international component, either because they involve basic research or because the commercial firms have overseas operations. For example, the automobile companies want to apply the new technology gained from their cooperative agreements with the laboratories in their European subsidiaries; in effect the American taxpayer will be subsidizing European automobile production.

PANEL III: TECHNOLOGY TRANSFER ISSUES

Technology Transfer: A Conceptual Framework for Evaluating Policy

Judith Reppy*

INTRODUCTION

Technology transfer issues have achieved a new saliency with the end of the Cold War and the downturn in military spending in the United States and elsewhere. Whether the issue is weapons proliferation, maintenance of the defense industrial base, dual-use technology, international competitiveness or conversion of military R&D facilities, questions about the nature of technology transfer and the conditions that favor it arise. In addition, of course, there is the whole set of questions concerned with technology transfer within the civil sector and with international technology transfer as an element of economic development. This paper, however, concentrates on issues of transfer of military technology to the civil sector in the United States, focusing on the case of the national laboratories.

Even though technology transfer programs are only a modest fraction of the national laboratories' budgets and activities, they represent an important institutional innovation, one that directly addresses the problems of conversion of the nation's technology base from military to civilian use. In this paper I review the understanding of technology transfer to be found in the economics literature, as supplemented with insights from the field of science and technology studies, and outline two opposing views on industrial policy. I then contrast the policy recommendations to be drawn from the competing theories, with special attention to cooperative research and development agreements (CRADAs). Finally, I raise some other questions about the current policy on technology transfer and ask how we will recognize success if it comes.

* The author wishes to acknowledge the helpful comments of Joseph Pilat and the Cornell "technogeeks," and the clipping services of Hugh DeWitt.

TWO THEORETICAL TRADITIONS

Within the economics literature on innovation and diffusion there are two schools of thought regarding the difficulty of technology transfer. In the first school, information is seen as a pure public good, with inventors unable to capture a reward for their efforts because of the ease with which others can acquire information about their inventions.[1] This line of reasoning provides the rationale for the patent system—which creates appropriability by conferring a temporary monopoly on the inventor—and for government investment in science—which helps to compensate for underinvestment by the private sector in research activities.

The well-known arguments about spin-off of military technology to the civilian sector fit in this school of thought. Despite the controversy surrounding the presumed importance of spin-off as a source of productivity growth in civilian industry, the concept itself has been remarkably under-theorized. Spin-off proponents have argued their case on the basis of a standard litany of success stories, while skeptics have asserted the irrelevance of most military technologies for civilian needs. The difficult empirical questions of the magnitude of the social benefits attributable to spin-off and its relationship to the costs of the military R&D program have scarcely been tackled, and the mechanisms for technology transfer are seldom explicitly discussed.[2] In most narratives of successful spin-off, military technology simply resurfaces in civilian guise, with little or no apparent effort on the part of anyone; frequently cited examples such as jet aircraft engines and communications satellites come to mind.

If this were the whole story we would not be worrying about how to promote technology transfer from the national laboratories: it would be happening by itself. There is plenty of empirical evidence, however, to support an alternative view of technology, one that emphasizes the

[1] For the classic treatment of information as a public good, see Kenneth Arrow, "Economic Welfare and the Allocation of Resources for Invention," pp. 609-626 in *The Rate and Direction of Inventive Activity*, National Bureau Committee for Economic Research (Princeton: Princeton University Press, 1962).

[2] Ulrich Albrecht, "Spin-off: A Fundamentalist Approach," pp. 38-57 in Philip Gummett and Judith Reppy, eds., *The Relations Between Defence and Civil Technologies* (Dordrecht: Kluwer Academic Publishers, 1988).

embedded nature of technology.[3] In this approach, new technology is not a matter simply of the kind of information that is available in journal articles or blueprints. Instead it includes much local knowledge and informal know-how, and technology flows involve the transfer of, or at least an understanding of, the tacit knowledge to be found in the context in which the technology was first developed. A particularly striking example of the importance of context to technology transfer can be found in the case of Roland II, a French air defense missile that was licensed to Hughes Aircraft in 1975 for production for the U.S. Army. Translating and transferring the technical data package (TDP) was a far greater task than had been anticipated, eventually costing $18 million.[4] Some of the difficulty came from the absence of equivalent military specifications and standards in the two countries and from different conventions in France and the United States for interpreting engineering drawings. More important, shop practices in the two countries differed, with the French relying on a tradition of craftsmanship rather than detailed specifications. Malone notes:

> Many other shop bench practices relied heavily on the craftsmen, thus they were not explicitly defined in a TDP as in US practice. Measures and measurements often had to be tediously derived from functional descriptions. Converting some of the drawings consumed four times more effort than anticipated. No single difference was overpoweringly difficult, but the total resolution of ROLAND'S technology transfer demanded more time, money, and skilled man-hours than anticipated.[5]

In this case of international technology transfer, the problems were particularly acute, requiring literal as well as metaphorical translation of the technical information. But the more general lesson holds: an investment of real effort and time is required for technology transfer, and absent that investment it is not likely to succeed.

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[3] See Giovanni Dosi, "Sources, Procedures and Microeconomic Effects of Innovation," *Journal of Economic Literature*, 26, (September 1988), pp. 1120-71.

[4] Daniel K. Malone, *Roland: A Case for or against NATO Standardization*, National Defense University Monograph Series no. 80-5 (Washington, DC: National Defense University Press, May 1980), p. 69.

[5] Ibid., p. 71.

The contextual elements of embedded technology probably transfer best through personal interactions; networks are important. In a study of the conditions of appropriability in U.S. industry,[6] for example, Richard Levin and his colleagues found that patent disclosure was not considered an effective means of learning about other companies' technology. Instead, firms relied on activities that required a larger investment—for example, reverse engineering or independent research and development—or involved interpersonal communication—for example, attending technical meetings or hiring employees away from the innovating firm.[7]

As we survey the debate over technology transfer from the national labs we can see traces of both of the concepts of technology outlined above. To the extent that the laboratories are seen as a world onto themselves, isolated by security classification and with a long-standing dependence on the Department of Energy for funding, the picture of technology as the product of local culture embedded in local practices seems relevant, and successful transfer will require "translation." In the defense industry there is a shared culture that includes a cost-plus mentality, emphasis on small-scale, customized production, the absence of marketing know-how, and a tendency to value high performance above other considerations such as cost or reliability.[8] All of these characteristics militate against a smooth meshing of defense capabilities with commercial needs, and in addition, there will be specific features unique to each firm or division that further distinguish its "indigenous" technical practices from practices elsewhere.[9]

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[6] Richard Levin, Alvin Klevorick, Richard Nelson and Sidney Winter, "Appropriating the Returns from Industrial Research and Development," *Brookings Papers on Economic Activity*, 3 (1987), pp. 783-831.

[7] A recent survey of chief technical officers of R&D-intensive corporations conducted by J. David Roessner yielded rather different results, with informal visits, professional conferences, and journal articles ranked higher than employee exchange as means of gathering outside technical information

[8] See, for example, the discussion in U.S. Congress, Office of Technology Assessment, *After the Cold War: Living with Lower Defense Spending*, OTA-ITE-524 (Washington, DC: U.S. Government Printing Office, February 1992), pp. 213-14.

[9] Charles Draper, for example, created a private language to discuss his theories, a language that was easily comprehensible only to those who had spent time in his laboratory. See Michael A. Dennis, "Our First Line of Defense: University Laboratories and the Making of the Postwar

Similarly, in the national laboratories the local culture is not immediately suited to technology transfer to the commercial sector. The obstacles include a large, entrenched bureaucracy that has been slow to downgrade its nuclear mission and that hinders the timely negotiation of cooperative agreements; pervasive security classification; unfamiliarity with the needs and constraints of private industry; a preference by the technical staff for working on their own pet projects; and a tendency to cast lab projects in terms of grand challenges rather than the more mundane problem solving of commercial work.[10] The importance of these bureaucratic and cultural obstacles to technology transfer has been at least partially recognized in the Department of Energy's new "Strategic Plan for Technology Transfer," which proposes to streamline laboratory procedures and give more autonomy to lab directors to negotiate with industry.[11]

Relatively neglected in the public discussions of technology transfer from the national labs is a recognition that local conditions in the receiving civilian firms are equally important in determining the success of technology transfer. Government policy has been based implicitly on a model of technology push, with little regard for demand pull or for the obstacles to successful transfer that may exist in industry.[12] The institutional features that can impede the transfer of technology out of the laboratories have their counterpart in the bureaucracies of large industrial firms, in the prevalence of the not-invented-here syndrome, and in the barriers to information flows between divisions within the firm as well as from the outside in. In addition, U.S. business firms are notoriously interested in short-term financial results to benefit shareholders rather than long-term strategies to build technical competence. While they may be eager to enter into cost-sharing arrangements to harvest technology from the national laboratories, it has yet to be

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American State," *Isis* (forthcoming 1994).

[10] Scott McCartney, "With Cold War Over, Los Alamos Seeks New Ways of Doing Business," *Wall Street Journal*, 15 July 1993, p. 1; Roger Werne, "Defense Labs Can Provide Economic Security," *San Francisco Business Times*, Week of August 20-26, p. 31.

[11] William B. Scott, "U.S. Labs Embrace Technology Transfer," *Aviation Week and Space Technology*, 139 (23 August 1993), pp. 64-66.

[12] National Academy of Sciences, Panel on the Government Role in Civilian Technology, *The Government Role in Civilian Technology: Building a New Alliance* (Washington, DC: National Academy Press, 1992), p. 16.

demonstrated that they will invest the financial resources needed to bring those technologies to the market.[13]

The alternative view, that of knowledge as the prototypical public good, can also be found in the debate over technology transfer policy. It would be a mistake to look for it in the rationale for funding the national laboratories, which is rooted in the claims of another type of public good—namely, national security—rather than in the argument that private industry will underinvest in science and technology. The distinction between the two arguments was obscured in the 1980s, when much technology policy was smuggled into the defense budget under the rubric of national security to get around the ideological objections of the Reagan and Bush administrations to government intervention in commercial markets. This obfuscation notwithstanding, the labs' fundamental mission is clearly national security; even the basic science programs at the labs have been justified on the basis of their contribution to the quality and morale of the staff performing the nuclear mission.[14]

Nevertheless, the attention paid to negotiation of patent rights in the cooperative research agreements between the labs and private companies attests to the prevalent belief that without such protection the lab technology could be easily exploited by all comers, that is, that the technology being transferred has the character of a public rather than private good.[15] Theoretically, the public good argument is strongest for basic research, which builds on a common pool of scientific knowledge and is usually freely available in scholarly publications. It may also apply to development of generic technologies—such as the development of composite materials or of new technology for manufacturing microchips—that enter into the development of numerous different final products. Note, however, that in this line of argument once a technology is

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[13] William Scott, "Tech Transfer Leadership Falls to Industry, Not Labs," *Aviation Week and Space Technology*, 139 (6 September, 1993), p. 32.

[14] See, for example, the letter from Hans Bethe, et al. in *The Bulletin of the Atomic Scientists*, 48 (November 1992), pp. 45-46.

[15] See U.S. General Accounting Office, *Technology Transfer: Constraints Perceived by Federal Laboratory and Agency Officials*, GAO/RCED-88-116BR (March 1988) and U.S. Congress, Office of Technology Assessment (OTA), *Defense Conversion: Redirecting R&D*, OTA-ITE-552 (Washington, DC: U.S. Government Printing Office, May 1993), pp. 114-17.

patented it is no longer a candidate for public funding, since private appropriability has been created.

In the case of military technology, of course, a much stronger argument can be made for public funding, since, as pointed out above, the entire military budget is justified by the fact that defense is a public good and is universally regarded as the responsibility of the state. This argument breaks down, however, when funding for research and development in military programs is justified on the grounds that they will have civilian benefits, that is, precisely at the point at which technology transfer is presumed to occur.

The public discourse on technology policy in the 1980s was affected by the tension between the apparent crisis in American economic performance, especially in high technology, and the Reagan-Bush administrations' adherence to the free market, which allowed only two reasons for government intervention: to support basic science, as a remedy for the market failure resulting from the status of information as a public good; and to support military technology as part of the state's responsibility for national security. In these circumstances it is not surprising that new categories were constructed to partake of the privileged status of science and military technology. Thus we have the rise of "pre-commercial" or "generic" technology, which claims for selected technologies the same status as public goods (and as recipients of government funding) that have long been accorded to basic science.[16] Similarly, "dual-use" became a popular phrase to describe technologies, such as micro-electronics and advanced materials, that are important in both military and civilian sectors, and the Department of Defense was regularly asked to fund development of these technologies under the rubric of national security.

Arguments that stretch the public goods justification for public funding for R&D beyond the category of fundamental research can be seen as simple opportunism on the part of the laboratories and private companies that stand to benefit by having the government pay for work that they will profit from. Alternatively, they may be viewed as a pragmatic recognition that in real life the activities of discovery and invention do not map neatly into the canonical categories of basic research, applied research, and development, so that a government policy that funds only a

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[16] See, for example, National Academy of Sciences, *The Government Role in Civilian Technology*, pp 19-20.

narrow range of activities may distort or truncate the very innovative activities that it seeks to encourage.[17]

Implications for Policy

I have discussed above two different ways of thinking about technological knowledge and the relative ease with which it can be transferred between institutions, in our case, between government laboratories and private firms. We can also distinguish two broadly differing schools of thought regarding the government's role in promoting technology transfer or intervening in the market to target specific industries or sectors in other ways.[18] Those who oppose a federal industrial policy argue that the decisions made by private firms in the marketplace yield better outcomes than political processes, which are susceptible to pork-barrel politics and bureaucratic rigidities, a position frequently summed up as "governments can't pick winners." Government support for education and basic scientific research is acceptable, but advanced development of civilian technology is a matter for private firms. This free market position dominated executive branch thinking during the Reagan-Bush administrations, and the few policy initiatives to aid civilian industry that emerged—e.g., SEMATECH—typically originated in Congress and were justified under the rubric of national security and funded in the Defense Department budget.

The Clinton administration is more closely identified with the school that believes that "governments make winners" and argues for a proactive government policy to promote technology development and industrial competitiveness. Proponents of this school point to the role that government policy has played in the economic success stories of Japan and the newly industrializing countries of the Pacific Rim and argue that, to be competitive in the new global environment, the United States must also devise government policies to promote new technology in industry. The technology investment project proposed by the President Clinton in February 1993

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[17] On the interconnections between science and technology, see Thomas P. Hughes, "The Seamless Web: Technology, Science, Etcetera, Etcetera," *Social Studies of Science* 16 (1986), pp. 281-92.

[18] Policies that have a more general effect, such as R&D investment tax credits or support for technical education, are not at issue here, although they could be part of an industrial policy, broadly construed.

reflects the new administration's willingness to involve the government directly in a range of activities, including encouraging government-industry partnerships to effect technology transfer from the government laboratories.[19]

We can construct a simple 2 x 2 matrix to clarify the relationship between these ideas and their implication for policy (see figure 1). The columns are the two theories of the nature of technology and the rows are the two opposing views of the appropriate role for government in promoting competitiveness.

Figure 1
Matrix of Policy Prescriptions

		Concept of Technical Information	
		Public Good	Embedded
Policy Stance	No intervention	1 Government funding for basic science and some "pre-competitive" technology. Patents important. No technology transfer policy.	2 Government funding for basic science only.
	Intervention desirable	3 Government intervention sanctioned, but only general guidelines.	4 Cooperative agreements and other policies to promote effective networks.

If one adopts a) the model of knowledge as a public good and b) a non-interventionist stance towards government policy (cell 1), then support for basic science, and possibly—as discussed above—for generic or pre-competitive technologies, and patent legislation are the only justified policies. In particular, there is no basis in this cell for technology transfer policies. Sub-

[19] Paul Proctor, "Clinton Offers U.S. Technology Plan," *Aviation & Space Technology*, 138 (March 1, 1993), pp. 18-19.

sidies for innovative activity are meant to repair the particular kind of market failure created by non-appropriability, but are not otherwise justified.

A public goods model plus interventionist stance (cell 3) generates support for government action beyond the support of basic science and patent laws, but it offers no guidelines as to what kind of technology transfer policies should be introduced, since the theoretical understanding of the nature of technical information denies the existence of a transfer problem.

The alternative model of embedded technological knowledge leads to different policy prescriptions. In the case of a non-interventionist stance (cell 2), there is no justification for any government policy beyond support of basic research, since this view of technology replaces the non-appropriability argument with a claim that technology is rooted in its specific context and not easily transferred. Thus patent protection becomes irrelevant, even for the so-called generic technologies.

For the interventionist, the embeddedness argument (cell 4) offers a prescription for specific kinds of government action to promote technology transfer. We have a different kind of market failure, one caused by institutional stickiness, which must be overcome by policies designed to encourage familiarity with the context in which the technology was developed and to provide for the transfer of tacit as well as overt knowledge to the receiving party. The current policies of the Clinton administration, such as cooperative research and development agreements (CRADAs), belong in this cell.

In evaluating different policy options, it is instructive to consider the case of the Defence Technology Enterprises (DTE), an organization set up in 1985 in Britain with the explicit purpose of facilitating technology transfer from the Ministry of Defence (MoD) laboratories to private industry.[20] Financial support for the organization came from a consortium of financial institutions, which expected to make a profit from licensing fees paid for the technology. DTE relied on engineers, known as "ferrets," who were placed in MoD establishments to identify promising

[20] See Bernard Herdan, "A UK Initiative for the Transfer of Technology from Defence to Civil Sector," in Philip Gummett and Judith Reppy, eds. *The Relations Between Defence and Civil Technologies*, pp. 166-79.

technologies and bring them to the attention of DTE's associate members, the potential users in the commercial sector.

Despite the identification of a large number of candidate technologies, DTE failed to achieve a sufficient number of successful commercializations to become itself financially viable, and it had wound down its operations by the end of 1990. Among the causes contributing to DTE's demise was the failure to recognize that technology transfer would require the virtual translation of military technology to a new setting, a process that required more time and money than the financial institutions that had joined DTE were prepared to invest. In addition, many of the most promising technologies were already under contract with private firms via long-standing arrangements between the research establishments and their established partners in the defense industry, and thus unavailable to DTE.[21] The history of DTE is a sobering reminder that the national laboratories may not be a cornucopia of unexploited technology ready for civilian use.

CRADAs

Cooperative research and development agreements (CRADAs) are one institutional response to the problem of effecting technology transfer from the national labs to private industry. Unlike DTE, which was marketing licenses to lab-developed technologies, these agreements provide for both the laboratory and the private organizations(s) to contribute personnel, equipment and financing to a research program that is of mutual interest. First authorized in the Federal Technology Transfer Act of 1986 and extended to DOE labs in 1989, CRADAs initially faced many roadblocks.[22] With the development of standard language and the granting of greater autonomy to lab directors to approve agreements, CRADAs have become the instrument of choice. At Los Alamos, for example, the number of executed agreements jumped from 2 in 1991

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[21] Graham Spinardi, "Defence Technology Enterprises: A Case Study in Technology Transfer," *Science and Public Policy*, 19 (August 1992), pp. 198-206.

[22] For a summary of the legislative history of CRADAs, see U.S. Congress, OTA, *Defense Conversion*, pp. 98-99.

to 29 in 1992.[23] By April 1993, 382 CRADAs had been signed by the 17 DOE laboratories.[24] The main obstacle to further growth in the number of CRADAs appears not to be bureaucratic red tape—although that still causes delays—but the fact that the laboratories have committed all of the available funds.[25]

One of the advantages of CRADAs over other forms of government-industry cooperation is the provision that protects information developed in the project from freedom of information requests for up to five years; that is, other firms cannot free ride simply by filing a request under the FOIA, and other government employees have access only under conditions of strict confidentiality. In addition, the lab can choose to grant exclusive patent rights on government-owned patents to its industrial partner subject to the government retaining a royalty-free license.[26] While these practices raise certain policy issues discussed below, they do serve to calm the fears of private companies that proprietary information will be disclosed as a result of entering into a cooperative arrangement with a national laboratory.

The advantages of CRADAs for technology transfer can be assessed by the standards suggested by the theoretical approaches outlined above. Since CRADAs promote interaction between the laboratory and industry scientists, they should allow for the translation of lab know-how into technology suitable for industry use. Because the private firms must contribute to funding the projects, they have an incentive to monitor effort; problems of moral hazard are lessened, if not eliminated.[27] Thus, the CRADAs seem well-suited to answer some—but not all—of the problems that arise in trying to design government policies that will elicit the desired behavior from private actors.

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[23] Information supplied by R.T. Tremper, LANL. Print-out dated 6/21/93.

[24] U.S. Congress, OTA, *Defense Conversion*, p. 104.

[25] Scott, "U.S. Labs Embrace Technology Transfer," p. 65.

[26] For a fuller discussion, see U.S. Congress, OTA, *Defense Conversion*, pp. 114-17.

[27] For the 42 CRADAs included in R.T. Tremper's print-out of 6/21/93, the laboratories are supplying 55% of the total funding.

What will be the effect of the CRADA activity on the laboratories as a whole? Should technology transfer be regarded as a transitory activity, a way of harvesting past investments in technology, or will the scientists and engineers at the laboratories take on a new role of technical consultants, turning the laboratories into "job shops"?[28] At the moment the size of the CRADA program is limited, and the majority of the government funds comes from the laboratories' budget for defense programs. If the program grows substantially it could be part of a re-invention of the national laboratories; if, on the other hand, it remains a minor activity, then we can question whether it can succeed, particularly if the bulk of the laboratories' activities continue to be conducted behind the wall of security classification.

Other Policy Issues

Identifying a theoretically-grounded justification for government promotion of technology transfer does not solve other difficult issues. Questions of equity, effectiveness, and accountability remain. Even if we accept the need for government intervention to promote national competitiveness, we must ask, For whose benefit? Should private rights be granted for technology developed at taxpayer expense? The current transfer mechanisms privilege some companies, particularly large companies, over others.[29] To the extent that companies are willing to invest in the follow-on activities needed to bring technology to market only if they are guaranteed the temporary monopoly that a patent confers, there is an argument for assigning private patent rights to assure that development. But it is also possible that companies are acting strategically, signing agreements with the national laboratories to insure that other firms do not have access to certain technological developments. In this case, only a private interest is served.

With every CRADA signed with a private company, other companies—both potential competitors to the laboratories in providing technology services and the competitors of the firm involved in the CRADA—are excluded from open access to that technology. The argument that

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[28] I owe the analogy to Hugh DeWitt.

[29] David Sims, "Bills Address How to Refocus National Labs," *IEEE Software Magazine* (July 1993), p. 101.

the national labs and their technical treasures should be exploited for the nation's sake does not really speak to this issue of access and equity.

A second issue is equally troubling. If CRADAs or other mechanisms for technology transfer that exist are successful, the policy that promotes them will be vindicated. But what counts as success?[30] So far the figure of merit appears to be the number of agreements signed, or, even more telling, the number of proposals submitted, which far exceeds available funds. It is not enough, however, to point to industry's willingness to engage in CRADAs, since the agreements carry a 50 percent subsidy. At that price a firm may propose an agreement for strategic reasons—to forestall a competitor—rather than because it intends to commercialize the technology. For individuals within the system, motivation may be similarly strategic. A CRADA protects a research program from being cut back or eliminated as the laboratory budgets decline, an advantage that is presumably apparent to scientists in both government and industrial laboratories. Unfortunately, the well-known difficulties of measuring the benefits of R&D apply, and any assessment of outcomes will necessarily be imperfect and open to varying interpretations.

Looming behind the question of accountability standards for CRADAs is the possibility of radically different uses for these resources in promoting technology, including removing the funds from the lab budgets and reassigning them to a different government agency and set of programs. Real success for the CRADAs would be laboratory technology commercialized and proven profitable in the market. It may be too early to expect results of this sort, but it is not too early to ask how we will recognize them if they occur.

CONCLUSIONS

I have argued that the intellectual underpinnings of the new policies for technology transfer lie in an understanding of technology as embedded in its local context, combined with an activist stance on industrial policy. The success of the new policies will depend on whether the laboratories can shed their cloistered character and cooperate in the translation of their technol-

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[30] Similar questions have been raised with respect to NASA's program for technology transfer. See U.S. General Accounting Office, "NASA Aeronautics: Impact of Technology Transfer Activities is Uncertain," GAO/NSIAD 93-137 (16 March 1993), pp. 7-8.

ogies to a commercial setting. It will depend equally on the demand of private firms for the technology, not just within the common culture of R&D laboratories, but also in corporate offices where decisions to bring technology to the market are made. Whether these conditions hold in the current situation is an empirical question, which I hope the panel of experts will address.

There are other important questions. Can fair access be guaranteed without overburdening the process for reaching agreements, which in the end must be between the laboratories and specific companies? What safeguards are there against opportunistic behavior on the part of individual researchers, seeking to safeguard their own projects from the budgetary axe, and strategic behavior on the part of firms, seeking to stake a claim to technology simply to block access by others? Finally, how shall we recognize success or failure?

PANEL III: TECHNOLOGY TRANSFER ISSUES

Chair: Joseph Pilat (Los Alamos National Laboratory and Cornell)

Background Paper: Judith Reppy, "Technology Transfer: A Conceptual Framework for Evaluating Policy"

Panel: Burgess Laird (Los Alamos National Laboratory)
Sharon Novak (Harvard Business School)
Gary Pagliano (Congressional Research Service)

PANEL PRESENTATIONS

Burgess Laird argued that cooperative research, not technology transfer should be the new mission for the laboratories. This mission requires a break with the old mindset of the cold war era, and a willingness to explore new paradigms. Up to now the typical CRADA has been a one-to-one, labs-to-industry agreement for three years, whose main beneficiary is the firm. In the short run it is important that the labs undertake such work, but there are problems in continuing to support CRADAs over the long run, since the focus is on transfer of already developed technology rather than developing new technology. He proposed instead that firms approach the labs as consortia to do projects with benefits flowing into the future. There will still be some opportunistic behavior on the part of the firms and researchers, but it will be balanced by the long term benefits. Hence, CRADAs are not an end to themselves.

He had the following answers to the questions posed in the background paper by Judith Reppy:

- Networks should be promoted to the extent that cooperation is possible. Grouping firms serve to align the supply side. We are moving towards an industrial policy; whereas in the past technology transfer was only an afterthought, new legislation has made a difference. As budgets increase, technology transfer will be taken more seriously.
- Consensus on technology "road maps" accepted by coalitions of firms can help the transfer process. The semiconductor industry has demonstrated this phenomenon with SEMATECH.

- You can mitigate opportunistic behavior, but you cannot eliminate it. Should we care? Yes.
- Issues of equity and access arise in the context of rivalry between competing firms; not all industries will support cooperative consortia. Some industries are natural oligopolies; for example, the limited market for supercomputers will support only a small number of producers.
- We won't know success by counting the number of CRADAs signed. There is a danger that there will be too much emphasis on tangible products, when some intangibles, such as access to lab facilities, are also important.

The central thesis of **Sharon Novak**'s remarks was that the national nuclear laboratories can play an important role in assisting U.S. companies attain global competitiveness in high technology sectors, but to do so there must be major changes in their conception of their mission, in their organization, their relationship to companies and their connection to the Department of Energy and other government agencies. Furthermore, they can succeed in their new role only if the government enunciates a clear national strategy for technological development.

She identified the following important causes for US economic decline: high priority to consumers and consumption rather than to producers and production; the lowest rates of savings and investment in the industrial world; a huge budget deficit; lower expenditure on civil R&D as a percent of GDP than in competitors Japan and Germany; and archaic antitrust laws that inhibit cooperation among firms for competitiveness.

National laboratories can make their resources—human and technological—useful for the development of commercial products in four ways:

- participation in high risk projects in which the research and capital costs are enormous, the payback a long way off, and the national interest at stake, i.e., projects with a strong flavor of public goods;
- help in projects in which industry can use laboratory state-of-the-art equipment, such as supercomputers, and thus avoid the high cost of purchasing it;
- serving as a natural location to pool human and capital resources from consortia of companies, universities, etc. to achieve technological breakthrough;

- serving as an ideal setting for the fusion of complementary technologies, which is becoming increasingly important commercially.

The national labs should be organized to permit much greater flexibility and industry participation in the selection and direction of their work. Within a broad framework of DOE oversight, the labs should have considerable autonomy in the management and conduct of cooperative projects with industry. Options for licensing and safeguards for intellectual property rights should be standardized, and collaborative opportunities with industry should be better publicized. Programs that encourage industrial exchange among lab scientists and partner firms as well as the hiring of managers with industrial experience should be encouraged in order to provide insight into company needs.

Gary Pagliano argued that it is important to put the labs' problems in the context of the current situation. The defense base is changing, there is a lot of talk on the need for a balance between the public and the private sector, and organizations in the defense industry are changing and will continue to change.

He summarized two major pieces of pending legislation that could answer some of the questions raised. In the House, the Brown Bill would clarify eight broad missions for the labs; establish procedures for evaluating CRADAs; create a new office in the DOE with an FY 1995 budget of $300 million to manage technology transfer; and set up 600 labs, with a new committee to coordinate these labs. Up to 20 percent of the labs' budgets would be set aside for collaboration, including collaboration with state and local governments.

In the Senate, Senator Johnston has sponsored a bill that will promote closer ties between the labs and industry. The bill, which is attached as an amendment to the DOD appropriation bill, calls for at least 20% of lab budgets to be spent on collaborations with industry and for DOE to establish intellectual property rights rules. Funding for these activities would increase from $100 million to $210 million, and $240-440 million would be set aside for joint ventures with nondefense companies involving dual use technology.[1]

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[1] Both the House and Senate legislation failed to pass in 1993 and remained pending 1994.

Congress has decided that the labs are a national asset and should be given time to adjust to their new circumstances. There are certain factors to keep in mind when evaluating the future of the labs:

- the results of the energy projects will not be obvious to the public;
- environmental clean-up is important—we don't know what is in the ground;
- in the field of transportation the recent deal with the automobile industry is a good model. The projected fuel savings supply the element of public good.

SUMMARY OF DISCUSSION (Anand Prakash)

The discussion took up issues posed by CRADAs, the role for the laboratories in economic competition, and different definitions of technology transfer and collaboration.

I. CRADAs

Concern was expressed by some of the panelists and members of the audience regarding the realities of the CRADAs. The labs need to address the question of what they are doing and how they are doing it. The proposal process for the CRADAs should be streamlined and standardized. Different labs have different programs for technology transfer, and not many companies know the differences between them and how to participate.

Some concern was expressed regarding the realities faced by people working under the CRADAs. Three main concerns were raised. First, as funding has decreased scientists have been asked to find CRADAs. Though some scientists have been very resourceful in searching out outside money and CRADAs, most working scientists have no prior experience in engaging in such activities, which were actively discouraged for most of the history for the labs. As the rules have been abruptly changed, many distinguished scientists are finding themselves superfluous.

Second, work done at the labs is expensive, with huge overhead costs because of the bureaucratic infrastructure that grew up around the nuclear weapons work. This means that the weapons labs will not be able to compete indefinitely with private R&D-performing companies if the subsidy to the labs is removed.

Third, some felt that if the labs are to continue as sources for new technology, they must maintain a strong base of real and fundamental research. This capability could be sacrificed under the CRADAs, which were seen as a way of sharing technology, but not adding to the technology base.

II. How important are the labs' missions?

There was a fair amount of consensus regarding the importance of the mission of the nuclear labs in the past for national security reasons. The government still attaches importance to this concern and so will keep the labs going for some time just on this ground, even if new missions cannot be immediately found. Some participants felt that the labs have a very important role to play in making U.S. industries competitive with Germany and Japan in high technology sectors. It was argued that there is a lot of short-term thinking on part of U.S. industries and that this can be rectified with the help of the labs. The mission of the national labs could be made more broad to encompass many items of national concern, such as energy, environment and transportation. The public good nature of investment in these projects makes the private sector investment in it sub-optimal.

III. Technology Transfer vs. Collaboration

Two different, if not contradictory, images of technology transfer emerged in the discussion. Some of the participants talked about the role of the labs as facilitating collaboration with industry. They argued that an expansive interpretation of technology transfer should be taken in order to eliminate opportunistic behavior and have benefits flowing into the future. The labs should provide the facilities in terms of personnel, machinery, etc. to industry to undertake research that is considered to be in the larger interest of the country. Others were talking about CRADAs as the mechanism for the transfer to private industry of technology researched in the national labs. It was argued that under this conception of technology transfer the benefits accrue mainly to individual firms rather than industry as a whole. It was pointed out, however, that the structure of CRADAs is consonant with the economic institutions in the United States and other capitalist economies. So long as individual property rights are important, single-firm agreements will be preferred.

APPENDIX A

For Once, A Peace Dividend[1]

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Basic research in the United States is in crisis. For half a century, the US has led the world in the creation of new scientific knowledge, in the invention of new technology, and in educating scientists and engineers. Unless we have strong leadership with clear vision, we shall lose that place. Once lost, it will be very difficult or impossible to regain, as other nations have learned that once stood at the cutting edge of science and technology.

The crisis has its roots in deep historic trends: the end of the Cold War, and systemic weaknesses in America's economy and society. The former has reduced the demand for military technology, for which we should be grateful. The latter has spawned the widely accepted misconception that governmental and corporate support for research should be devoted only to projects that promise a quick payoff clearly visible to tax payers and stockholders.

In Chinese, the word "crisis" means danger *and* opportunity. Fortunately, we have the opportunity: to redirect the nation's huge investment in the nuclear weapons laboratories towards research aimed at serious problems that we are sure to face as a society and in the global market place, but that universities and private industry do not have the resources to address.

The weapons labs—Los Alamos, Livermore and Sandia—are organizations of unrivalled technical power. They employ a large number of highly skilled scientists and engineers and have unique, sophisticated facilities, at an annual expenditure of about one billion dollars each. Their main job until now, the development of nuclear weapons, is greatly diminished by the demise of the Soviet threat and the moratorium on nuclear testing. Most of these people are eager to turn their talents to non-military problems of vital interest to society and industry. The

[1] An edited version of this essay was published on the op-ed page of the *New York Times* on 6 December 1993.

national labs are, therefore, ideally placed for the applied research which all agree must be strengthened if the US is to be competitive.

To some extent, the weapons labs have already moved in this direction by tackling problems of current interest to industry. But a huge laboratory like Los Alamos cannot long live on outside jobs that appear haphazardly. It must have steady support from government for a long-term major civilian objective to replace the role played until now by nuclear weapons.

How should the nature of this work be determined? A Presidential task force, appointed in consultation with Congress, should be created to answer this question, and to recommend means for ongoing supervision. Its members should come from industry, academia, and most importantly, from the laboratories, because it is essential that the laboratories' innate enthusiasm be skillfully tapped.

In my view, the research projects should be of vital interest to the nation's future and be long-range, with a time frame of 10 to 20 years. One example is the need to develop new technologies to free ourselves from our dependence on fossil fuel, especially for road transport. Related to this is the effort to design fuel cells in which liquid fuel is directly converted into electricity when then drives the engine; such fuel cells would greatly increase the fuel efficiency and decrease pollution. Another project would be making high-temperature superconductors applicable in industry. Micro-robotics could be very useful in medicine. A project which is already underway is decongesting city traffic, by ingenious application of supercomputers. Industry is unable to tackle such long-range problems, no matter how important. The national laboratories are used to working on such a time scale, and have a tradition of working in large interdisciplinary teams towards a challenging common goal. Moreover, they can do work that would benefit an entire industrial sector, without the limitations posed by antitrust law.

Once the general plan has been approved, the laboratories should be left largely to themselves, without the micromanagement from administrations and Congress that has become endemic and is stifling creativity.

The laboratories would then remain the national assets they have been, rather than being an embarrassment due to the end of the Cold War. They are far easier to convert to peacetime work than most factories, because their main assets are people—people whose skills are very flexible. In short, this conversion would be a true peace dividend.

This plan would not only meet the national need for more applied research, it should also lay to rest the misguided if well-intentioned effort to divert funds from basic long-term research towards short-term applied research. The National Science Foundation (NSF) has been under increasing Congressional pressure to divert a large part of its relatively modest resources to applied research, even though the corporate leaders on last year's Commission on the Future of the NSF opposed such a move.

When NSF was founded in the 1950s, it was clearly understood that pure research is the basis from which the most important and unexpected inventions flow. NSF remains the only government agency whose primary purpose is the support of basic research and the advanced training of research scientists and engineers. The wisdom of the political leaders who created NSF has been amply demonstrated: Many technologies common today were unknown at that time, such as lasers and MRIs, and dozens of Nobel Prizes have been won by American scientists.

That level of enlightened leadership is needed again: an understanding that scientists pursuing basic research cannot, by definition, specify with bureaucratic precision when and how they will attain their goal. New scientists and engineers are best trained by engaging in basic research and such training is invaluable for successful applied research. The unquestioned need for more long-range applied research can be met by the remarkable organizations that we have acquired at great expense, the nuclear weapons laboratories.

APPENDIX B

Defense Conversion and the Future of the National Nuclear Weapons Laboratories

Room G-08, Uris Hall
Cornell University
October 1-2, 1993

Workshop Program

Friday October 1

2:00 p.m.-4:30 p.m. Panel 1: What is the Nuclear Mission?

Chair:	Kurt Gottfried
Background paper:	Lawrence Scheinman and Joseph Pilat
Panel of Experts:	Paul Brown, Paul Cunningham, Richard Garwin, Jonathan Medalia

Saturday October 2

9:00 a.m.-12:00 noon Panel 2: Planning for Conversion

Chair:	Susan Christopherson
Background paper:	Michael Dennis
Panel of Experts:	Maurice Katz, Paul Robinson, Bill Weida

1:30 p.m.-4:30 p.m. Panel 3: Technology Transfer Issues

Chair:	Joseph Pilat
Background paper:	Judith Reppy
Panel of Experts:	Burgess Laird, Sharon Novak, Gary Pagliano

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Cornell University

Future of the National Nuclear Laboratories

Cornell University
October 1-2, 1993

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