GRIs in the United States: Policy Directions Old and New†

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Abstract

The United States National Innovation system has many distinctive aspects and its government research institutes (GRI's) play a variety of important roles within the overall system. This paper reviews issues pertaining to U.S. GRI's but within the broader concept of US science and technology policy. After presenting an overview of the GRI's in this broader context, the paper presents a brief historical analysis of changes in the roles and deployment of U.S. GRI's. After identifying unique features of GRI's (ones that separate the U.S. GRI's from other nations) the paper concludes by identifying the ways in which the U.S. experience may be relevant to other nations such as Korea. The lessons include the competition-cooperation with large-scale and multidisciplinary university research centers, the use of GRI's to promote sharing and efficiencies in fundamental scientific equipment and resources, and the ability of GRI's to accelerate the development of science and technology.

KEYWORDS: government research institute, national innovation system, university research center, innovation, science policy history

1. INTRODUCTION

This paper examines government research institutes (GRI's) in the US by providing a brief historical overview, explaining their role in the U.S. National Innovation System (NIS) (Freeman, 1995; Mowery, 1992), and discussing factors that may or may not be unique about U.S. GRI's and the U.S. NIS. The paper concludes with some thoughts about the elements of U.S. GRI's that can be applicable to other nations such as Korea and possible future directions for U.S. GRI's and the implications of those directions for the U.S. as well as the rest of the world.

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GRI's in the United States must be assessed in light of the role and scope of other research and development (R&D) actors and institutions in the U.S. (Brooks, 1996; Crow and Bozeman, 1998). We consider that most R&D spending is in the private sector, (2) that only about 30% of federal government spending is performed by GRI's of any sort, and (3) that large and well resourced GRI's (the ones that contribute to the NIS rather than to the smaller and immediate needs of their parent agencies) receive only about 10% of the federal budget to show that the importance of context is evident (AAAS, 2011). The GIS is a significant but not a dominant actor in the U.S. National Innovation System (NIS). Thus, this paper begins with some brief comments on the U.S. NIS and the contemporary science and technology policy domain.

1.1 The Size and Scope of the U.S. NIS

The most obvious aspect of the NIS of the United States is its unprecedented scope and size. The U.S. NIS includes approximately 16,000 R&D labs (defining and "R&D lab" as a free-standing research unit that has more than 30 research professionals working in science and engineering) (Crow and Bozeman, 1998). However, government research labs represent a relative small proportion of these 16,000, albeit an especially important one. There are more than 750 government laboratories (only a small percentage of the NIS) that are especially important. In the first place, some of these are among the largest research institutions in the world, several having more than 1,000 science and engineering (S&E) employees. An examination of the government research institutes of the federal government (state and regional governments also support GRI's) shows more than 60,000 S&E employees with an R&D budget in excess of $35 billion (AAAS, 2011).

A GRI in this paper refers to: federal government-owned laboratories managed by the federal government, federal government-owned laboratories managed by contractors (so called "GOCOs"), and federally-financed research and development centers (FFRDC). The term FFRDC refers to hybrid organizations that typically have an industry or university sector manager (such as Battelle, Inc. or the University of California). The largest GRI's are often FFRDC's.

1.2 The US Science Policy Consensus and the Role of the GRI

President Barack Obama is the latest president to assert that the U.S. "economic engine" runs on science and technology; a belief shared by nearly all U.S. policy-makers. The view of science and technology as a crucial component of economic growth and national well-being unites even disparate administrations. For example, despite government differences in taxation, economic regulation, and health care (to name just a few of the issues that separate Obama and the George W. Bush administrations) budgets and policies for science generally remained stable. Sharp differences on science and morality (for example views on stem cell research) should not confuse the respective administrative views on the economic impact and importance of science and technology. Since the 1940's the string remains unbroken; American administrations believe in science and technology, especially in the power to make things better. (*Note: for a brief historical timeline of US science policy developments see the Appendix to this paper*).

Arguments against a simplistic "linear model"[2] (for an overview of the model and a review of criticisms see Godin, 2006) notwithstanding, there is abundant evidence that science and technology produces the knowledge critical for economic and social change. Whether one considers case studies that link knowledge to the production to social utility (e.g. Jewkes, Sawers, and Stillerman, 1969; U.S. Department of Defense, 1969; Roessner, et al., 1997; Feller, Ailes and Roessner, 2002) or whether one focuses on quantitative estimates of the value and use of science and technology (e.g. Utterback, 1974; Mansfield, 1995, 1998; Buxton, et al., 2004; Fontes, 2005) there is every reason to believe in the fecundity of science and technology. Reasonable observers disagree at the margins on the impact of science and technology, but any doubters who feel that science and technology is hyped beyond their potential impact face a formidable accumulation of contrary evidence. Indeed, even the much maligned linear model (a model almost all agree is an oversimplification) turns out to have at least some validity. Studies (e.g. Narin, et al., 1997) show that technology development, as measured by patents, relies significantly on basic science, though the relationships between knowledge and commercial application present challenges to those desire to measure them (Cassiman, et al., 2008).

The "easy consensus" about overall objectives and the wisdom of investing in science and technology is explained less by shared values or priorities than by a common tendency to pass along science policy directives to the mid levels of bureaucracy. Presidents like science and technology, but rarely want to be directly involved. Whether one measures presidential science ennui in terms of measured column inches of speeches, presidential leadership (or its lack of) in developing new policies for science and technology, or the limited power and attention gained by science advisors, one concludes that most U.S. Presidents share the view that science is a "good thing" but one best left to scientists and science bureaucrats. Give the scientists the money (maybe a little more now in this time of boom and a little less in this time of recession, but give them what you can) and then let them decide what needs to be done with it. This is not to say that Presidents are wholly inattentive to science, but rather that they are largely inattentive to specific content. One of the most important things to know about U.S. Science policy, is that Presidents and congressional leaders attend to science policy in broad outlines, and only episodically. All but the most important policies are made in a few large and powerful bureaucracies that are remarkably stable.

1.3 The Role of GRI's in the NIS

U.S. science policy is in general strongly influenced by bureaucratic policy making with only occasional attention by political leaders and it is especially so in the case of GRI's that are largely ignored by political leaders. The only major exceptions to the "hands off" rule are when a scandal develops (e.g. espionage, misuse of funds) (see Hanson, 1992) or when a particular leader has a major GRI facility in their political district. Otherwise, the policy realm of which GRI's operate in

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[2] The linear model is the idea basic science leads directly to applied science that leads directly to the development of technology and its diffusion into products.

is largely invisible to political leaders as well as the public.

This does not mean that GRI's have a particularly high level of autonomy within the U.S. NIS. First, they are responsible to government agencies for "staying on mission" and the development of research and technology related to the agencies' policies. Second, their contractor managers in some cases manage the GOCO's closely. Finally, most of the funds received by many GRI's are allocated by program managers of the agencies and must be attuned to the programmatic priorities of the managers.

Despite (or in some cases because of) the managerial design of the GRI's, many play a distinctive role in the U.S. NIS. larger and higher capacity GRI's are often tasked with special emphases and funding in mega-science and technology initiatives such as the National Nanotechnology Initiative. In this sense, the GRI system provides a strategic balance useful for accelerating the accomplishment of national programmatic goals in science and technology.

2. PROFILE OF GRI's

We can distinguish two broad categories between GRI's of government laboratories wholly owned by the federal government: those managed by agencies and those that consist of government personnel. Most of the smaller, more applied laboratories are of this type that serve a narrow conception of their parent agency's mission. FFRDC's are more important from the standpoint of innovation and contribution to the U.S. NIS. However, the GRI establishment in the U.S. also include R&D facilities owned and operated by state governments in addition to the federal government owned and operated facilities.

2.1 Government-Owned and Operated Intramural Research Institutes and Programs

With few exceptions, government owned and operated GRI's in the U.S. do not make notable contributions to leading edge innovations or to highly complex or multidisciplinary missions (the exception: NIH intramural labs). They consume a majority of the R&D funds devoted to GRI's; however, in most cases the work performed is a direct service to the agency they serve. Thus, any strategic focus requires attention to the FFRDC's that include (among others) the high capacity DOE multi-program national laboratories (the national labs).

2.2 The FFRDC

The term federally financed research and development center (FFRDC) recently came into common use; however, it actually originated during World War II. Originally called "federal contract research centers," the FFRDC, according to the Federal Acquisitions Register (Section 2.101) (see https://acc.dau.mil/CommunityBrowser.aspx?id=434942) is:

Sponsored under a broad charter by a Government agency (or agencies) for the purpose of performing, analyzing, integrating, supporting, and/or managing basic or applied research and/or development, and that receives 70 percent or more of its financial support from the Government; and --

1. A long-term relationship is contemplated;
2. Most or all of the facilities are owned or funded by the Government; and
3. The FFRDC has access to Government and supplier data, employees, and facilities beyond that common in a normal contractual relationship.

A key element of the FFRDC is that it is a hybrid organization that benefits from some private sector-like procurement and personnel rules.

Typically, FFRDCs are operated, managed, and/or administered by a university or consortium of universities, other not-for-profit or nonprofit organization, or an industrial firm as an autonomous organization that do not have shareholders or partners. FFRDCs have many different designs (Crow and Bozeman 1998). FFRDC's include government-owned contractor-operated facilities, a structure that dates back to World War II during which AT&T voluntarily managed weapons labs to promote efficiency by bringing industrial management experiences to these entirely new institutions. FFRDC's also include university affiliated research centers (UARC), large facilities financed wholly or primarily by federal funds; however, operated by and often located within major universities. In a later section of this paper I discuss extensively an especial variety of UARC, the MMURC, that has been a competitor to and, at the same time, a partner with many of the traditional large government laboratories, both government-owned and FFRDC.

The key aspect of the FFRDC is a close relationship between it and the sponsor, a relationship that is presumed to have the following advantages (https://acc.dau.mil/CommunityBrowser.aspx?id=434942):

- Adaptability – ability to respond to emerging needs of their sponsors and anticipate future critical issues
- Objectivity – ability to produce thorough, independent analyses to address complex technical and analytical problems
- Freedom from conflicts of interest and dedication to the public interest – independence from commercial, shareholder, political, or other associations
- Long-term continuity – uninterrupted, consistent support based on a continuing relationship
- Broad access to sensitive government and commercial proprietary information – absence of institutional interests that could lead to misuse of information or cause contractor reluctance to provide such information
- Quick response capability – ability to offer short-term assistance to help sponsors meet urgent and high-priority requirements

Each of the major federal R&D funding agencies has FFRDCs. Table One provides a list of the most prominent FFRDC's that include all large-scale GRIs that make significant contributions to the U.S. NIS.

TABLE 1. Funded R&D Centers (FFRDCs)
[current as of July 2012, Table based on page downloaded from http://www.nsf.gov/statistics/ffrdclist/start.cfm

- **Aerospace Federally Funded Research and Development Center** *Administrator:* The Aerospace Corporation *Location:* El Segundo, CA Sponsor: Department of Defense, Department of the Air Force
- **Ames Laboratory** *Administrator:* Iowa State University of Science and Technology *Location*: Ames, IA *Sponsor*: Department of Energy
- **Argonne National Laboratory** *Administrator:* UChicago Argonne, LLC *Location*: Argonne, IL Sponsor: Department of Energy
- **Arroyo Center** *Administrator*: RAND Corp. Location: Santa Monica, CA S*ponsor:* Department of Defense, Department of the Army
- **Brookhaven National Laboratory** *Administrator:* Brookhaven Science Associates, LLC Location: Upton, NY *Sponsor:* Department of Energy
- **Center for Advanced Aviation System Development** *Administrator*: MITRE Corp. *Location:* McLean, VA Sponsor: Department of Transportation, Federal Aviation Administration
- **Center for Communications and Computing** Administrator: Institute for Defense Analyses Location: Alexandria, VA *Sponsor:* Department of Defense, National Security Agency/Central Security Service
- **Center for Enterprise Modernization** *Administrator*: MITRE Corporation Location: McLean, VA *Sponsor:* Department of the Treasury, Department of Veterans Affairs, Internal Revenue Service
- **Center for Naval Analyses** *Administrator*: The CNA Corporation Location: Alexandria, VA *Sponsor:* Department of Defense, Department of the Navy
- **Center for Nuclear Waste Regulatory Analyses** *Administrator:* Southwest Research Institute Location: San Antonio, TX Sponsor: Nuclear Regulatory Commission
- **Fermi National Accelerator Laboratory** *Administrator*: Fermi Research Alliance, LLC Location: Batavia, IL *Sponsor:* Department of Energy
- **Frederick National Laboratory for Cancer Research** *Administrator:* SAIC-Frederick Inc., a subsidiary of the Science Applications International Corp. Location: Frederick, MD *Sponsor*: Department of Health and Human Services, National Institutes of Health
- **Homeland Security Studies and Analysis Institute** *Administrator:* Analytic Services, Inc. *Location*: Arlington, VA *Sponsor*: Department of Homeland Security, Science and Technology Directorate
- **Homeland Security Systems Engineering and Development Institute** *Administrator*: MITRE Corp. *Location:* McLean, VA *Sponsor*: Department of Homeland Security, Science and Technology Directorate
- **Idaho National Laboratory** *Administrator:* Battelle Energy Alliance, LLC *Location*: Idaho Falls, ID *Sponsor:* Department of Energy
- **Jet Propulsion Laboratory** *Administrator*: California Institute of Technology *Location*: Pasadena, CA *Sponsor:* National Aeronautics and Space *Administration*
- **Judiciary Engineering and Modernization Center** *Administrator*: MITRE Corp. Loca-

tion: McLean, VA *Sponsor*: United States Courts, Administrative Office of the United States Courts

- **Lawrence Berkeley National Laboratory** *Administrator*: University of California *Location*: Berkeley, CA *Sponsor:* Department of Energy
- **Lawrence Livermore National Laboratory** *Administrator*: Lawrence Livermore National Security, LLC *Location:* Livermore, CA *Sponsor:* Department of Energy
- **Lincoln Laboratory** *Administrator:* Massachusetts Institute of Technology *Location:* Lexington, MA *Sponsor*: Department of Defense, Assistant Secretary of Defense for Research and Engineering
- **Los Alamos National Laboratory** *Administrator:* Los Alamos National Security, LLC *Location*: Los Alamos, NM *Sponsor:* Department of Energy
- **National Biodefense Analysis and Countermeasures Cente**r *Administrator*: Battelle National Biodefense Institute *Location*: Frederick, MD *Sponsor*: Department of Homeland Security, Science and Technology Directorate
- **National Center for Atmospheric Research** *Administrator:* University Corporation for Atmospheric Research *Location*: Boulder, CO *Sponsor*: National Science Foundation
- **National Defense Research Institute** *Administrator:* RAND Corp. *Location:* Santa Monica, CA *Sponsor*: Department of Defense, Office of the Under Secretary of Defense for Acquisitions, Technology and Logistics
- **National Optical Astronomy Observatories** *Administrator:* Association of Universities for Research in Astronomy, Inc. *Location*: Tucson, AZ *Sponsor*: National Science Foundation
- **National Radio Astronomy Observatory** *Administrator*: Associated Universities, Inc. *Location:* Charlottesville, VA *Sponsor*: National Science Foundation
- **National Renewable Energy Laboratory** *Administrator:* Alliance for Sustainable Energy, LLC *Location*: Golden, CO *Sponsor*: Department of Energy
- **National Security Engineering Center** *Administrator:* MITRE Corp. *Location:* Bedford, MA, and McLean, VA *Sponsor:* Department of Defense, Office of the Under Secretary of Defense for Acquisitions, Technology and Logistics
- **Oak Ridge National Laboratory** *Administrator:* UT-Battelle, LLC *Location*: Oak Ridge, TN *Sponsor*: Department of Energy
- **Pacific Northwest National Laboratory** Administrator: Battelle Memorial Institute *Location*: Richland, WA *Sponsor:* Department of Energy
- **Princeton Plasma Physics Laboratory** Administrator: Princeton University *Location:* Princeton, NJ *Sponsor:* Department of Energy
- P**roject Air Force** *Administrator:* RAND Corp. Location: Santa Monica, CA *Sponsor:* Department of Defense, Department of the Air Force
- **SLAC National Accelerator Laboratory** *Administrator*: Leland Stanford, Jr., University Location: Stanford, CA *Sponsor*: Department of Energy
- **Sandia National Laboratories** *Administrator*: Sandia Corporation, a subsidiary of Lockheed Martin Corp. *Location:* Albuquerque, NM *Sponsor:* Department of Energy
- **Savannah River National Laboratory** *Administrator:* Savannah River Nuclear Solutions,

LLC *Location:* Aiken, SC *Sponsor:* Department of Energy

- **Science and Technology Policy Institute** *Administrator:* Institute for Defense Analyses *Location:* Washington, DC *Sponsor:* National Science Foundation
- **Software Engineering Institute** *Administrator:* Carnegie Mellon University *Location*: Pittsburgh, PA *Sponsor:* Department of Defense, Assistant Secretary of Defense for Research and Engineering
- **Studies and Analyses Center** *Administrator:* Institute for Defense Analyses *Location:* Alexandria, VA *Sponsor:* Department of Defense, Office of the Under Secretary of Defense for Acquisitions, Technology and Logistics
- **Thomas Jefferson National Accelerator Facility** *Administrator:* Jefferson Science Associates, LLC *Location*: Newport News, VA *Sponsor:* Department of Energy

Figure 1 below shows that FFRDCs consume a relatively small share of the federal R&D budget; however, more than 22% of funds go to intramural federal agency research (typically directly owned government labs or R&D programs) and only 10.5% goes to FFRDC's. However, this figure is deceptive because of partnering with various laboratory types, "work for others" (contracts of one lab with another or with an agency) and the transfer of some intramural research resources to FFRDC's. Nevertheless, from the standpoint of performing R&D, the amount provided to universities and industry exceeds the role of the FFRDC as a performer.

FIGURE 1. Federal Obligations for Total Research, by performer: FY 2004 (Current US dollars in millions)

PERFORMER	OBLIGATIONS	% DISTRIBUTION
Total research	53,357.7	100.0
Intramural	12,085.2	22.6
Industry	6,782.7	12.7
Universities and colleges	22,699.1	42.5
FFRDCs	5,614.4	10.5
Nonprofit institutions	5,216.4	9.8
State governments	532.9	1.0
Foreign	427.0	0.8

FFRDCs = federally funded research and development centers.

NOTES: Because of rounding, specific details may not equal the stated total. The percentage of total research ($53.4 billion) was computed using US dollars in thousands. Intramural includes the costs associated with the administration of intramural and extramural programs by federal personnel and actual intramural performance.

SOURCE: National Science Foundation/Division of Science Resources Statistics, Survey of Federal Funds for Research and Development: FY 2004, 2005, and 2006.

3. A BRIEF HISTORY OF GRI's IN THE UNITED STATES

Science policy is generally untouched by the most prominent elective offices and is especially the case when science policy issues involve the status and activities of GRI's. Nevertheless, we can identify some extremely broad trends that have a fundamental shaping effect on U. S. GRI's. In this section, I briefly review some of those trends, but only as a matter of context. There are many other more extensive treatments available on the history of science policy in the U.S. (e.g. Brooks, 1996).

3.1. 1945-1965: World War II Afterglow

As has been widely discussed (see Crow and Bozeman, 1998 for an overview), much of U.S. Science policy and policy related to GRI's, originated during and immediately after World War II. Science and the Manhattan Project were viewed as having played a vital and instrumental role in winning the war. It was not lost on policymakers that a highly organized set of new and advanced research institutions had played a role in nourishing the science that led to the creation and deployment of the atomic bomb. There was a widespread view among policymakers (as well as leading scientists) that these new establishments could be put to good use in the future with respect to defense and national security missions as well as civilian applications such as the peaceful use of nuclear energy. Thus, the government owned and contractor operated system that had been developed during the war by laboratories such as Los Alamos that served as a blueprint for the organization of multi-program (national) government laboratories.

Throughout the United States, support for science in GRI's and in university laboratories grew steadily for more than 15 years after the war. Many refer to this as the Golden Age of Science in the United States and was certainly the Golden Age for the GRI. There was a high degree of public and political support for these research institutions and a widespread belief and their ability to solve national problems. As the Cold War continued to escalate, the national laboratory system was seen as a major aspect of science and technology policy as well as an important instrument for defense and national security. Given the extent to which the United States budget (particularly during that era) was dominated by the US Defense Department, it is easy to see why and how the laboratory system expanded and flourished during this period.

Elsewhere (Crow and Bozeman, 1998), I refer to these early policy rationales for US GRI's as the mission paradigm. According to this view, dominant in the early history of large-scale GRI's, the chief role of GRI's should be to perform R&D in the service of well-specified missions wear there is a national interest not easily served by private R&D or where serious market failures have occurred. The most important element of the mission policy philosophy is defense and national security-related R&D; however, such missions such as energy production and conservation, medicine and public health, space, and agriculture have expanded along with the role of the GRI's.

The next significant era of change in U.S. GRI's, during the 1970s, was not a new way of thinking about science policy and GRI's but, rather, a new way of thinking about the expansion of existing line missions under the mission paradigm. This new mission was a and tents and multifaceted concentration on a wide variety of energy related topics beyond the traditional nuclear energy mission that the labs had traditionally provided.

3.2. 1970’s: Energy Scarcity and DOE reorganization

Except for the organization strongly affiliated with the Atomic Energy Commission, the GRI's had not played the major role that was expected for National Energy Policy. Before the 1970s, the GRI's, especially the large multi-program laboratories under the umbrella of the Atomic Energy Commission, were largely dominated by physics research (Buck, 1983). Many of these GRI's nuclear physics centers featured the ‘Civilian Prince’ operating alongside the ‘National Security King’. As the shockwaves of the earliest widely perceived energy crisis hit the shores of the United States, it became clear that nuclear energy was part of the nation's national security concerns. During the Carter Administration, there was widespread change in the structure and emphasis of GRI's, with the most extensive change centering on multi program national laboratories. Many of these existing GRI's were retooled to expand their energy missions towards new concerns such as synthetic fuels, solar energy, fuel cells, and energy conservation. New GRI's were created such as the Solar Energy Research Institute.

During this period, the Department of Energy was created from a variety of existing organizations that included the Short-Lived Energy Research and Development Authority, the still powerful Atomic Energy Commission, and energy research programs from the National Science Foundation. It was expected that the Department of Energy and the GRI's associated with the Department of Energy would maintain a trajectory that would include a wide energy resource portfolio. However, for a number of reasons (having to do chiefly with partisan politics) the energy focus of the Department of Energy became highly unstable under Democratic administrations that emphasized alternative fuel and Republican administrations that emphasized carbon-based fuel and nuclear energy. One result was that the policies and programs of the GRI's entered an ongoing period of great fluctuation.

3.3. 1980’s and Beyond: Competitiveness and Cooperative R&D

Another source of controversy in the United States is the extent to which GRI's should play a prominent role in the promotion of industrial competitiveness and industrial policy (Papadakis, 1992; Bozeman and Pandey, 1994). During the late 1970s and the early 1980s, a period widespread concern about the declining economic competitiveness of the United States (see: M.I.T. Commission on Industrial Productivity, 1989; National Academy of Sciences, 1978; National Governors' Association, 1987; President's Commission on Industrial Competitiveness, 1985; Council on Competitiveness, 1993) featured a considerable consensus on how U.S. GRI's could fulfill this role. Due to this bipartisan consensus, a number of pieces of legislation were passed to enhance the role of GRI's in the promotion of economic development.

As noted elsewhere (Crow and Bozeman, 1998), the 1980’s witnessed the development of a new cooperative technology paradigm that was as close as the United States had yet come to the development and endorsement of industrial policies. The cooperative technology paradigm is an umbrella term for a set of values that emphasize cooperation among sectors (industry, government, and university) and cooperation among rival firms in the development of pre-competitive technologies. Kash and Rycroft (1998) have provided strong arguments for cooperative technology policy approaches.

Among the policies (that could be considered as the most prominent of the cooperative technology paradigm) are policies: to change patent policy to expand the use of government technology (Patent and Trademark Laws Amendment, 1980), relax anti-trust legislation that promotes cooperative research and development (R&D) (Link and Bauer, 1989; National Cooperative Research Act of 1984), establish research consortia and multi-sector centers (Smilor and Gibson, 1991), and alternative guidelines for the disposition of government-owned intellectual property (Bagur and Guissinger, 1987).

The related cooperative technology development policies that have attracted the most attention are those pertaining to domestic technology transfer, especially the use of federal laboratories as a partner for the commercialization of technology (Herrmann, 1983; Rahm, Bozeman and Crow, 1988; U.S. General Accounting Office, 1989). Previously aloof from commercial concerns (indeed prohibited by law from developing technology specifically for private vendors) the legislation of the 1980's gradually changed the mission, tenor, and climate of federal laboratories (Bozeman, 1994) and (to some extent) the companies interacting with the labs (Roessner and Bean, 1991). The intellectual property dictum "if it belongs to everyone, it belongs to no one" began to take hold as government labs increasingly moved from a sole focus on public domain research to a mandated role as a technology development partner for industry.

3.4. 1990’s and Beyond: Reforms, Political Turmoil, and Redirection

The enthusiasm for the cooperative technology paradigm and the role of GRI’s and economic development began to wane substantially in the 1990s. There remains significant policy remnants and the GRI’s still have programs for cooperative research and technology; however, the level of policy interest in government laboratory technology transfer has declined steadily. In part, this seems to be explained by the dominance of the Republican leadership and the U.S. Congress. Over the past 2 decades, Republican leaders have strongly resisted and expanded role for the GRI's (except for those members of Congress who have major installations in their districts). The antipathy began in the 1990’s and has not ceased. Indeed, in early 1997, the Republican majority of the 105th Congress issued a declaration to end corporate welfare. Using the market failure argument, they targeted cuts in a number of federal programs designed to stimulate new technology development in critical industries that included all programs directly linked to civilian technology development at the NIST and DOD.

Changing views about the role of the GRI’s should not be thought of as owing entirely to partisan political disagreements. In 1994, the bipartisan report by the Secretary of Energy Advisory Board (U.S. Department of Energy, 1994) on the future of the Department of Energy national laboratories (The Galvin Commission report) emphasized that many national labs had strayed from their traditional energy and defense related missions and that any future work in technology development and commercialization should flow directly from those missions. This represents a sharp reaction against policy initiatives and program expansion under the cooperative technology paradigm. Simultaneously, the counter-reaction to “dual technology” initiatives (working on defense and civilian applications at the same time) at the Department of Defense had a similar attitude that the defense mission comes first and that efforts based on future progress may well undermine the defense mission.

GRI’s have not played so prominent a role in economic development as many had hoped during the early years of the cooperative technology paradigm; however, it the case that many GRI’s (particularly the national laboratories) remain quite active in technology development, licensing, and transfer. Table 1 below (based on the most recent generally available data) shows that federal laboratories filed more than 5000 patents in 2009. To provide a benchmark, this figure does not diverge significantly from the number of patents filed by the top 300 universities in the United States.

TABLE 2. Federal Laboratory Technology Transfer FY 2009

All Federal Labs:

Invention disclosure and patenting		Licensing		Collaborative relationships for R&D	
Inventions disclosed	5,454	All licenses, total active in fiscal year	7,567	CRADAs, total active in fiscal year	6,015
Patent applications	1,768	Invention licenses	3,804	Traditional CRADAs	3,546
Patents issued	1,391	Other intellectual property licenses	3,775	Other collaborative R&D relationships	7,454

Source: Science and Engineering Indicators, 2012

3.5. 1990’s to today: MMURC (University Competitors)

One of the major changes in GRI’s over the past two decades is the development of what are essentially competitive research centers and universities, along with an expectation that GRI’s will help breakdown any barriers for cooperative work between universities and government facilities. An understanding of the evolution of GRI’s in the United States requires some background on the development of these new large-scale research centers in U.S. universities. Indeed, some are of the opinion that with the great expansion of university capacity, technology, and large-scale resources, that the need for government laboratories and related GRI’s is greatly diminished and, related, that resources for GRI’s should largely be confined to defense and national security.

The new institution we have elsewhere (Bozeman and Boardman, 2003; Boardman and Bozeman, 2007) referred to as the Multipurpose Multidiscipline University Research Center (MMURC) became prominent in the 1980’s and especially the 1990’s among the 150 or so US research universities as they responded to a variety of program initiatives, ones chiefly centered at the US National Science Foundation.

The MMURC has ushered in a massive change for the science and engineering units in U.S. universities and has changed university administrations enormously. Twenty years ago, the focal administrative unit for almost all U.S. university researchers was the academic department (Geiger, 1993). Within the academic department (an organization devoted chiefly to teaching and administration of curricula) research activities were generally decentralized and focused on relatively narrow disciplinary objectives that aimed at the publication of articles in peer reviewed scientific journals. Individuals were able to gain tenure and continue a research livelihood by this currency. The management tasks were relatively simple ones two the extent that research could be said to have been managed, typically these included supervising a small team of graduate students or postdoctoral researchers on tasks directly related to the production and distribution of research. The job of the academic researcher was to do research and (if a faculty member) to teach and attend to the routines of faculty governance and services. Every couple of years it was necessary for the researcher to traverse the federal grants system in an effort to sustain funding; however, academic research was a professional enterprise entailing little bureaucracy and minimal management for the most part. Indeed, many chose academic careers, as opposed to more lucrative industrial research, because of the greater autonomy and decentralization of academic research. To the extent that academics were entrepreneurs, they were typically working autonomously and in small teams and not at the behest of the university administration.

Today's academic research landscape is quite different, and a new more centralized, multipurpose, and managerially complex research system has been in place for more than twenty years. Small science is still very much with us; however, the majority of grants remain relatively small and principal investigator-initiated ones. Small science now coexists with complex MMURCs that have almost as much in common with large-scale industry research units or national laboratories as with traditional academic science. While the MMURC has proliferated for some time, many represent relatively modest departures from traditional academic research organization designs. Many MMURCs are independent from departments, but simply provide a separate organization to support disciplinary researchers in pursuit of traditional research and publishing activities. However, we are especially interested in a particular type of URC, one that is multidisciplinary and multipurpose. These MMURCs are more complex as they are organized around research topics rather than disciplines, they have strong inter-institutional ties and often including researchers from industry and from more than one university. Of especial importance, the MMURCs present quite different and particularly interesting policy and management challenges.

The MMURC has become the policy instrument of choice for public officials and policymakers looking for solutions to large-scale science and technology problems that require an integrated research approach. Often, MMURCs are created to play leading roles in programs that are critical to a national interest that was historically the province of the federal laboratory system.

In some respects, MMURC's are the new national laboratories. To some extent, this is a direct result of disappointment with GRI's and the federal laboratory system. Despite the longstanding reliance on federal laboratories to perform interdisciplinary, problem-driven science and technology, dissatisfaction with the federal laboratories has grown, exacerbated perhaps as the end of the Cold War led to the widespread perception that the nuclear umbrella and mutually assured mass destruction were no longer keys to national security. When the federal laboratories took on such missions such as technology transfer and environmental remediation, some believed this was more a sign of mission drift than of adaptation. A series of blue ribbon panels deplored the labs' alleged sense of a lost mission, deplored their decline in science and technology capacity, and questioned the need for their continued existence.

Are MMURCs the “new national laboratories?” If the criterion is a leadership role in national science and technology initiatives, then the answer is affirmative; however, universities are not yet entirely comfortable with this relatively new role. While some aspects of research universities are changing at a dazzling pace, many elements of universities are the same as in the past. The disciplinary orientation, educational functions, and reward systems of universities differ little today from those of the 1920s. The administrative structure of many universities was developed to manage curricula and many research administration structures have been added haphazardly, responsive to such jolts as changes in intellectual property rights, federal research accounting, and the commercial enterprises of universities.

The MMURC came to prominence in the early 1980s, with the National Science Foundation (NSF) leading the way, especially through the creation of Engineering Research Centers. While the NSF has continued it leadership role with this research institution innovation, many other federal agencies have since developed MMURCs and others are contemplating similar measures. Likewise, state governments have developed MMURCs, often as a means to lead economic development initiatives.

It is certainly debatable whether the MMURC can perform all of the civilian science and technology missions previously performed by the national laboratory system; however, they do have many of the same characteristics of large GRI's. This includes expensive equipment and technology, multidisciplinary teams linkages among institutions (not only universities, industries, and some government laboratories), and a mix of basic and applied research. These institutions based and universities might have advantages with respect to human capital; however, the GRI's might have an advantage with respect to flexibility, lack of time spent on teaching missions, obtaining competitive tenure, and promotion. There is no typical MMURC and they are quite diverse (such as the Center for Ultrafast Optical Science at the University of Michigan with links to many other institutions) and should shed some light on these institutions, their differences, and similarities with GRI's.

4. WHAT IS A MMURC? EXAMPLE: THE CENTER FOR ULTRAFAST OPTICAL SCIENCE

While there is much diversity among MMURCs, one that is not atypical is the NSF-sponsored Center for Ultrafast Optical Science (CUOS) at the University of Michigan (http://www.engin.umich.edu/research/cuos/). CUOS is a research facility in charge of national and international research leadership, the production of lasers at the one terawatt level, and laser pulses as short as six femtoseconds (6 x 10-15s) for a variety of scientific and technological applications. CUOS owes allegiance to no single discipline and includes twenty-six faculty researchers from a wide variety of disciplines and departments, as well as more than twenty visiting researchers from industry, government, and other universities. CUOS researchers have published more than 400 scientific papers since the founding of CUOS in 1991. However, technical application activity is no less important for CUOS than fundamental research; in addition, research by CUOS has led to new developments in laser-based microsurgery. The designation as an NSF Science and Technology Center, and the $3 million per year funding of CUOS, requires leading edge research as well as industrial outreach and leadership in education that includes the training of doctoral researchers as well as undergraduates and high school students. The NSF Science and Technology centers are also expected to provide leadership for the hiring and training of women and minority scientists. Like many other new university research centers, CUOS is extremely complex and multifaceted with little resemblance to a traditional academic department or research laboratory. It is not like the Physics or Chemistry Department in function, resources, mission, or longevity.

The CUOS facility is the only one of perhaps 2000 university research centers (Florida and Cohen, 1999); however, only about 400 are of the scale and scientific and organizational complexity to be classified as MMURCs (the organizational type of especial interest here).

5. DISTINCTIVE OR UNIQUE ASPECTS OF U.S. GRI’s

The section below considers possible implications of the US experience with GRI's. The system of GRI's has evolved a great deal since World War II decades. There are lessons to be learned, many of them relevant to the United States and its future directions for science and technology policy; in addition, some are relevant to other nations such as South Korea. These are not all positive lessons because sometimes the most instructive lessons come from failure.

Before examining possible implications of the U.S. Experience with GRI's, it is useful to consider some methods in which the U.S. system is quite distinctive and not a positive model for the national innovation systems of other nations.

The amount of money devoted to GRI's in the United States surpasses that of most other nations; in addition, the scope, size, and diversity in the U.S. GRI system is unique. The previous section on institutional change in U.S. universities shows that it is not possible to understand the role of the GRI without understanding their place in the U.S. national innovation system, especially their interactions with universities and industry. In particular, there are more than 6000 United States colleges and universities and implies that there is a degree of scientific and technical human capital in the United States that is not found elsewhere. Most nations and their strategic planning for science and technology policy cannot afford to be as haphazard and undirected as the United States has historically been. The United States has had an extremely difficult time making strategic choices for its GRI's (and for science policy in general) and in most instances it has not paid a heavy price because the national innovation system is sufficiently massive that it desperately needed technical work that is accomplished with minimal direction. This can be a productive system and it is also a system that requires massive resources.

There are many bases of resources for scientific and technical activities in the United States to me: in addition, there are overlooked assets and the United States that provides a great wealth of scientific talent from immigrants to the United States (either permanently are for doctoral education and postdoctoral education). Some nations are beginning to challenge the United States with respect to the use of nonnative scientific talent and it remains the case that foreign scientist are very much a deep reservoir of support for the U.S. National innovation system. GRI's have particularly benefited from a reverse brain drain. Many foreign nationals are brought to work at the GRI's that provide a great reservoir of talent; however, they also bring some complications for GRI's that are focused on defense and national security.

The U.S. policy for its national innovation system is best described as no policy at all. It is certainly the case that there are specific and important science and technology policies that include some of those briefly reviewed above. However, the system relies on little rational planning or integration (Lane, 2008). In some ways this bottom-up autonomy has proven advantageous. However such a system can only be effective with the assumption of continued growth and massive investment. It is perhaps for this reason, that the strategy in public policymaking for science and United States (including the GRI's) is not a model easily applied to any other country. However, there is no reason to have an entirely applicable holistic model in order to glean specific lessons from the U.S. Experience.

6. CONCLUSIONS: POSSIBLE “LESSONS LEARNED” FROM U.S. GRI

In contemplating the relevance of the US experience to South Korea, we must first ask if the two systems are so different as to defy any useful comparison. True, the systems are different; however, it is often possible to learn from the accomplishments and mistakes of a very different political and policy systems in order to tailor the lessons to an individual context.

• *Experience of URCs and MMURCs*

One of the most important and unusual features of the role of GRIs in the U.S. is the dynamic tension between larger GRIs (especially the FFRDCs) and the major research centers of the U.S., the ones referred to as MMURCs. Few other nations have invested significant research capacity in universities as has the U.S.; in addition, university centers play roles that many nations reserve for GRIs. If there is any single most important lesson from this organizational approach it is the value of vesting national priorities for research in universities with the subsequent expectation that one result will be enhanced scientific and human capital due to the melding of education and research. Related, the use of GRIs as specialists in technology development and in accelerated research dovetails with the special competences of universities.

• GRI’s and National Defense

A significant percentage of resources invested in U.S. GRI’s (especially FFRDC’s) directly support military development and national defense. This explains in part the strong interest in “dual use technology” and technology commercialization from national defense oriented GRI’s. One lesson, is that organizational difficulties and inefficiencies are a natural concommitant to this effort.

• Power of Diversity and Scope

No nation has the diversity of the U.S. NIS or so many actors playing so many different S&T roles. However, one result of the scope of the NIS is a good deal of redundancy and overlap between the GRI’s and universities as well as among the GRI’s themselves. This attribute has led to some major criticisms of the GRI’s and a call to rationalize their missions. However, it is arguably a strength of the U.S. NIS. In almost any technical realm, there is a degree of overlap where multiple institutions simultaneously pursue similar goals; however, bureaucrats and policy-makers do not like overlap and may explain the effectiveness at generating innovations at multiple sites.

• Partnerships and Inter-sector Flexibility

The various complex organizational arrangments, management schemes and acquisitions regimes of the U.S. GRI often contributes to red tape and overcontrol of particular projects at particular sites. However, these same schemes are complex in part because they are created to enhance the ability of research insitutions to partner, regardless of sector or management type.

• Centralized Equipment and Resource Sharing

Related to the above point, the GRIs of the U.S. have (since their inception) operated under assumptions that they would host extremely costly equipment and facilities and that they would promote resource sharing. To a large extent, this goal has been realized and has been highly beneficial. More recently, the great expansions of advanced equipment and technology resources at universities have mitigated the importance of the traditional role of GRI’s; yet, it remains a significant one.

The U.S. GRI’s and the U.S. NIS are unique in many important ways; however, they at least provide a model for comparison. The utility of that model does not suffer from the particulars of U.S. GRI’s organization: in addition, activities are not easy to import to other nations that have different resources and different comparative advantages.

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APPENDIX

1940—National Defense Research Committee

1941—Office of Scientific Research and Development established

1945—Science: The Endless Frontier. This report to President Roosevelt by Vannevar Bush, the Director of the Office of Scientific Research and Development, is one of the first attempts to outline a national science and technology research and development enterprise. Included is a discussion of rationales for investing in research and development in addition to administrative and policy details on the responsibilities and structures of government. This document later motivated, in part, the establishment of the National Science Foundation. In the end, only certain parts of Bush's vision were adopted.

1946—Atomic Energy Commission (AEC) is established. Upon establishment, the AEC was charged with the peacetime development of atomic science and technologies. While much of their resources were directed towards defense related issues, the AEC played a central role in fostering a civilian nuclear industry, first by developing industrial collaborations and then by lobbying for provisions in the Atomic Energy Act (1954) to allow private and public collaboration in nuclear energy. (Buck 1983)

1946—Office of Naval Research

1946— President's Scientific Research Board established. The Truman administration lobbied Congress to create a National Science Foundation (NSF) with special responsibilities to provide research support to the Executive Office of the President (EoP). After initial attempts to establish a NSF failed in Congress, and seeing the need to better understand the US R&D enterprise, the Truman's executive office worked towards putting together a special task force to review government research and development activities. The taskforce (officially called the President's Scientific Research Board) included representatives from all major agencies and cabinets with significant R&D activities. In 1947, their report, Science and Public Policy, was released. It is considered one of the most comprehensive reports on the status of US science and technology research and development activities.

1946—Agriculture Research and Marketing Act. Prior to the 1946 legislation, Congress has passed a range of agriculture research and marketing legislation, all oriented towards making food prices lower and eliminating agricultural production surpluses. However, the 1946 Act took a signification departure from the standard model by providing for a National Advisory Committee of farmers, industry representatives, and experimental stations to propose and review USDA research projects. Additionally, USDA began adopting contract research models and focusing efforts towards regional issues and building resources for extension stations.

1948—National Institute of Health becomes National Institutes of Health. The National Institute of Health was created by the Ransdell Act in 1930 but its organization history dates back to the early 1800s. In its 1930 form, the NIH conducted fellowships for research into basic biology and medical problems. The establishment of other health research organizations (including those dedicated to mental health, dental disease and heart disease) coupled with the expansion of federal funding for research, motivated congress to change "Institute" to "Institutes" in the National Heart Act of 1948.

1949—Federal Council for Science and Technology is established. President Eisenhower, created the Federal Council for Science and Technology through an executive order and gave it the responsibility to promote coordinated policy planning by Federal agencies heavily involved in scientific research and development. This represents one of the many attempts to bring together Federal agencies in science and technology policy making.

1950—The National Science Foundation is created. The National Science Foundation was created by the National Science Foundation Act in 1950. Its mission is to "promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense." Initially envisioned as the leading scientific research organization, the Foundation's scope had already been encroached on by other research organizations federal agencies such as the NIH, the DOD, and the Atomic Energy Commission (AEC). Since its establishment, the research portfolio of the NSF has significantly expanded.

1954—Agricultural Trade, Development, and Assistance Act. The Agricultural Trade, Development, and Assistance Act of

1954—laid the foundation for an international food aid program commonly known as "Food for Peace." While certainly an international aid measure, this program was also championed as a pathway to U.S. access to international food markets.

1954—Atomic Energy Act of 1954. The Atomic Energy Act of 1954 is the first nuclear regulatory legislation that allowed for and promoted the civilian use of nuclear energy. It also laid the foundation—legislatively and programmatically—for international nuclear energy research and development collaborations. The 1954 act was an amendment to the Atomic Energy Act of 1946.

1954—First thermonuclear device detonated by the U.S.

1957—Successful Soviet launch of the Sputnik I. The success of Sputnik is regarded as the beginning of the Space Race. The capacity to launch satellites into space was seen as an indication that the Soviets could soon send ballistic missiles to North America. The U.S. responded to the launch by immediately funding a range of satellite projects. Sputnik also reinforced an effort to gather information on Soviet technologies and played a central role in the establishment of new organizations.

1958—Defense Advanced Project Agency established. Initially established as the Advanced Research Projects Agency (ARPA), the organization was tasked to rejuvenate defense science and technology capacities. The establishment of DARPA can be considered one of the Federal level organizational responses to Sputnik. DARPA is a granting agency, meaning it funds research rather than conducts it.

1958—National Aeronautics and Space Administration is established. The National Aeronautics and Space Administration (NASA) is another organization whose establishment can be attributed to the US response to Sputnik. NASA is well known for its space programs but its mission is much larger. Congress, in creating NASA, envisioned an organization that would "provide research into the problems of flight within and outside the Earth's atmosphere, and for other purposes" (US Congress 1958). NASA responsibilities include engagement with research on the fundamental properties of space, geology, satellites, and a range of other issues. Unlike DARPA, NASA also conducts research in addition to funding it.

1961—First American in Space. Alan Shepard pilots the Freedom 7 to become the first American in space

1962—Office of Science and Technology is created. The Office of Science and Technology was created in the Executive Office of the President (EoP) to advise the White House on scientific issues, primarily oriented towards space issues that included the US-Soviet Space Race. The Office of Science and Technology is the predecessor to the Office of Science and Technology Policy (OSTP)—the current EoP science policy advisory organization.

1966—Cotton Research and Promotion Act. The preeminence of cotton as the preferred material for clothing and textiles was threatened in the 1950s by the emergence of synthetic-petroleum based materials. The success of these materials was attributed to systematic research and promotional activities of market firms (large chemical companies). It was argued that the smaller U.S. cotton firms lacked a centralized capacity to conduct research and promotional activities.

Subsequently, Congress passed the Cotton Research and Promotion Act in 1966 and created a mechanism to "enable cotton growers to establish, finance, and carry out a coordinated program of research and promotion to improve the competitive position of, and to expand markets for, cotton" (7 U.S.C. 2101-2118, Public Law 89-502).

1966—Food for Peace program allows enriched and fortified foods

1966—Laboratory Animal Welfare Act passed. The Laboratory Animal Welfare Act (including its amendments in 1970, 76, 85, 90, 2002 and 2007) is the only federal legislation on the use of animals for experimentation. It requires research institutions to have an Animal Care and Use Committee to ensure that the design features of the legislation are fully and properly carried out. The Act has undergone several revisions to broaden the scope of animals covered. The legislation is enforced by the US Department of Agriculture (USDA).

1969—Mansfield Amendment. The Mansfield Amendment is a provision of the Defense Authorization Act of 1970 that restricts DoD research and development funding (through DARPA) to projects with direct military application and eliminates the range of more basic scientific research that DARPA had previously supported. The amendment was highly controversial within the scientific community. Proponents of the policy argue that the National Science Foundation (NSF) would pick up the newly unfunded DARPA work (a claim that never full came to fruition).

1969—National Environmental Policy Act. The National Environmental Policy Act (NEPA)+ created the Council on Environmental Quality (CEQ), required that environmental impact statements be prepared for major federal initiatives thought to have environmental implications. It was the first explicit step towards a national environmental policy. Compared to subsequent environmental legislation, NEPA is considered fairly straightforward and succinct. It is regarded as one of the more fundamental environmental policies.

1970—Environmental Protection Agency created. The early 1970s were marked by a range of fairly high profile environmental policy issues. The establishment of the EPA is one product of this. Championed by President Nixon, the EPA took over existing water and air quality regulatory and enforcement missions of other federal agencies and reinforced the policies surrounding them. The first EPA director, William D. Ruckelshaus, envisioned the agency as more than a mediator between government and industry by helping Americans develop a comprehensive environmental ethic.

1972—Office of Technology Assessment (OTA) established. The Office of Technology Assessment (OTA) was created to provide Congress (members and committees) with unbiased and authoritative analysis of technologically and scientifically complex policy issues. The OTA was a pioneer in the development of the process of "technology assessment" an idea that has seen widespread global adoption. The OTA was defunded in 1995. Its abolishment was somewhat controversial and several groups (that included members of congress) have argued for its return.

1972—Tuskegee Study Ethical Violations Exposed. Medical researchers working for the Public Health Service withheld treatment from African American patients with syphilis for years in an effort to study the effects of the disease on untreated patients. Exposure of this practice led to reform on policy guiding research working with human subjects.

1973—First Asilomar Conference. A concerned scientist, Paul Berg, recognized the potential catastrophic consequence of using microorganisms in scientific research and hosted a conference for scientists, ethicists, lawyers, and physicians in Asilomar, California.

1974—Energy Reorganization Act. The Atomic Energy Commission (AEC) was established in 1946 and tasked with directing federal civil and military nuclear energy and weapons research. With the emergency of private corporation collaboration on nuclear energy issues, the AEC took on a regulatory function that was quickly criticized. The Energy Reorganization Act dissolved the AEC and distributed its responsibilities to the Nuclear Regulatory Commission (NRC) and the Nuclear Research and Development Administration.

1975—Second Asilomar Conference. Paul Berg, after hosting a conference on laboratory biosafety in 1973, organized a second conference to focus specifically on recombinant DNA (rDNA). Scientists, lawyers, physicians, and ethicists created recommendations for working with rDNA and sent them to the National Institutes of Health (NIH).

1976—National Science and Technology Policy, Organization and Priorities Act (PL 94-282) established the President's Council on Science and Technology and the Office of Science and Technology Policy (OSTP).

1977—Department of Energy established. The Department of Energy (DOE) was created in response the Energy crisis and President Carter's desire to consolidate the Nuclear Regulatory Commission (NRC) and the Nuclear Research and Development Administration (NRDA) into a Cabinet level agency. Thus, the DOE absorbed the newly created NRC and NRDA. This reorganization was created under the Department of Energy Organization Act.

1979—Smallpox eradicated. Smallpox, an acute infection caused by the variola virus, killed a third of those infected. An eradication program organized by the World Health Organization and supported, in part, by the US, was effective in eliminating the naturally occurring cases of the disease. This is considered one of the greatest achievements in medicine.

1979—Three Mile Island. A partial meltdown of the Three Mile Island Nuclear Generating Station near Harrisburg Pennsylvania caused widespread concern over nuclear energy safety. This event was followed by the emergence of many anti-nuclear energy groups, lawsuits, and policy change considerations. It also had widespread implication for civilian nuclear power industries around the world and slowed growth in opening new plants.

1980—Bayh-Dole Act passed. The University and Small Business Patent Procedures Act (commonly referred to as the Bayh-Dole Act) gave research organizations intellectual property control of their work conducted under federal funding. The economic, scientific, and organizational impact of Bayh-Dole has been the subject of research for quite some time. While much of these impacts are not well understood, it is generally thought that Bayh-Dole has been helpful for university research through the provision of additional revenue for foundations that stimulate university-industry collaborations.

1980—Stevenson-Wydler Technology Innovation Act.

1980—U.S. Supreme Court rules that genetically engineered micro organisms are patentable.

1982—First genetically engineered (GE) crop produced (a tomato).

1982—White House Science Council established.

1985—Ozone hole discovered.

1986—Federal Technology Transfer Act.

1988—First patent for a genetically engineered animal.

1990—President's Council of Advisors on Science and Technology Created.

1**995**—Office of Technology Assessment (OTA) closed. The Office of Technology Assessment (see 1972, above) was closed by congress under Republican leadership. Proponents of the closure argued that OTA work duplicated work being done by other agencies and made it redundant. Some low-level talks of reinstating the OTA have existed since its closure. Occasionally, these ideas emerge in popular media outlets.

2000—Biomass Research and Development Act.

2001—National Nanotechnology Initiative approved.

2003—21st Century Nanotechnology Research and Development Act.

2005—Energy Policy Act passed with profound implications for agriculture due to biofuels.

2007—America Competes Act.

2007—Human Genome. First complete genome of an individual human was mapped.

2009—American Recovery and Reinvestment Act.