Biowarfare Lessons, Emerging Biosecurity Issues, and Ways to Monitor Dual-Use Biotechnology Trends in the Future

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INSS Occasional Paper 61

September 2005

USAF Institute for National Security Studies
USAF Academy, Colorado

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FOREWORD

We are pleased to publish this sixty-first volume in the *Occasional Paper* series of the United States Air Force Institute for National Security Studies (INSS). In it, Helen Purkitt makes three important contributions to our understanding and policy approach to the dangerous and important issues surrounding advances in biotechnology and threats of biowarfare and bioterrorism. She outlines clearly and systematically some significant lessons from the former biowarfare programs in Iraq and South Africa, providing real-world lenses into what were active programs in developing states. She follows by raising several important issues that are emerging in biotechnology developments across developing states, particularly in Africa. Finally, given the emphasis being placed on the biotechnology sector worldwide, and the problems associated with detecting and monitoring weapons programs disguisable among commercial, dual-use facilities and processes, she suggests some novel approaches to monitoring biotechnology development in hopes of identifying and tracking programs of interest. The biological weapons threat is complex, and it is not adequately addressed to date by any of the existing nonproliferation or counterproliferation efforts, which gives special significance to examinations such as that presented in this paper.

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EXECUTIVE SUMMARY

The study summarizes policy lessons for future efforts to monitor possible covert biological warfare programs based on recent investigations of past Iraqi and South African covert biowarfare programs. This comparative case study approach identified several commonalities in past biowarfare programs in developing countries. One was a tendency of governments to recruit some of the brightest graduate students studying in several different fields of science and send them abroad for advanced studies at western universities. This trend changed dramatically after the September 11, 2001 attacks in the United States, and it is now much more likely that future scientists working for government-sponsored bioweapons programs or for terrorist groups in the developing world will receive their advanced training at non-western institutions in Asia, Africa, and Latin America.

A second commonality is that covert biological weapons research and development efforts in several developing countries have focused on exploiting readily available, naturally occurring pathogens for use as weapons of mass disruption or terror, in addition to efforts to develop sophisticated, genetically modified, weaponized organisms delivered in sophisticated delivery systems that approximated the weapons development pattern in the United States and the former Soviet Union. Both the Iraqi and South African former biowarfare programs relied heavily on open-source literature to secretly develop biological pathogens at multiple dual-use civilian facilities. This diffusion of covert research and development facilities is likely to increasingly in the future as mobile equipment and production facilities are now much more readily available for sale to any interested buyer. While these trends will make it difficult to detect preliminary covert biowarfare-related research and development, the full-scale production of biowarfare weapons will continue to be difficult to hide.

Both the Iraqi and South African cases documented that no single control strategy was entirely effective at stopping covert biological research and development. However, a combined approach based on import controls, sanctions, good intelligence on the ground from bilateral sources, and continuous international inspections that was backed by a strong international consensus (in the case of Iraq) was remarkably effective at disrupting, slowing down the research and development process, and substantially raising the cost of conducting covert biowarfare programs. The final lesson that emerged from both cases is the fact that it continues to be difficult to control the movements of former biowarfare scientists and technicians.

The second section of this study identified and discusses new biosecurity issues that emerged since September 11, 2001. This project, based on interviews with a variety of experts in the United States and earlier interviews with South African experts and government officials, documented that experts and policymakers in the developed and developing world held very different views on important biosecurity issues. Recent efforts in the United States have focused on better ways to control and manage: 1) peer review biological publications with possible biowarfare applications, 2) the flow of foreign graduate students in the physical sciences studying in the US, and 3) government-funded research using select agents. These security issues increasingly collide with the economic development goals embraced by many public and private actors in developing countries who are trying to increase civilian biotechnology research and development capacity across several different sectors in their country in order to produce high-valued biotechnology exports and jobs. The result is a host of new economic and security issues that will not be easily resolved. Several examples of future biosecurity issues are presented based on recent efforts by South Africa and other African countries to participate in the global technology revolution. The paper concludes with a typology and some possible indicators and methods that may be useful to monitor emerging dual-use biological proliferation threats in the future.

BIOWARFARE LESSONS, EMERGING BIOSECURITY ISSUES, AND WAYS TO MONITOR DUAL-USE BIOTECHNOLOGY TRENDS IN THE FUTURE

INTRODUCTION

This study was completed during 2004 at the US Naval Academy. The report had several objectives. First, it summarizes some patterns that emerged from recent investigations of the Iraqi covert biological weapons (BW) program and how it evolved over time. The purpose of the analysis is to identify "lessons learned from Iraq's BW program" that may be useful for understanding future biological weapons proliferation threats throughout the world. While it may be too soon to develop broad policy lessons from the Iraqi case, several key insights have already come to light from earlier UN and more recent US-led investigations that will be useful for understanding similarities and differences in how covert biowarfare programs evolve in the developing world.

Second, the report identifies three important current issues in biosecurity in the United States and some trends in civilian biotechnology in the developing world that should be of greater interest to proliferation analysts in the United States. The original plan for this research was to assess the feasibility of a set of policy recommendations developed at the end of an earlier report.[1] However, it soon became clear that researchers in the United States are focused on very different issues when they discuss current and future biotechnology research and proliferation issues. Consequently, this research focused on summarizing the key issues of concern to scientists in the developed world and key trends that may be developing in many nation-states in the developing world.

Third, the report identifies new types of actors and presents a typology of countries in the world based on their involvement in civilian biotechnology research and development commitment to biological non-proliferation norms. These analytical constructs may help future efforts to monitor trends in civilian biotechnology worldwide by identifying some of the key actors and locations where dual-use biowarfare research is likely to occur.

The report concludes by summarizing the most important trends in biotechnology related to dual-use research programs and recommends that the United States government focus more on ways to monitor trends at the junction of civilian biotechnology and dual-use proliferation threats.

LESSONS FROM IRAQ

It is too soon to develop definitive policy lessons from the Iraqi effort to develop covert biological weapons. However, several insights have already emerged that may prove useful for understanding future patterns of covert biowarfare programs throughout the developing world. This section describes some key aspects of the Iraqi covert biological weapons program over time. Special attention is paid to comparing the Iraqi and South African programs because both of these developing countries had the requisite scientific and technical base to develop sophisticated covert R&D programs, both were loosely run programs where a great deal of power resided in the hands of program managers rather than senior politicians, and both programs were widely thought to be among the most sophisticated programs in the developing world at the time of their demise.

Policy Lesson #1: Recruit the "best and brightest" graduate students from several fields (i.e., human and animal life science) and send them abroad for training relevant to chemical-biological programs.

A common characteristic of the Iraqi biowarfare program, when compared to other covert biological programs initiated by countries in the developing world during the 1960s and 1970s, was the fact that many members of the first generation of professionals who were recruited into covert biological warfare programs went abroad for advanced studies or for shorter-term training programs.[2] This trend of sending selectees to the United States or to Europe was the dominant pattern during the first phase of the Iraqi secret biological program that ran from about 1960 to about 1985. According to the recently released Inspector General's report, widely referred to as the Duelfer Report, junior Iraqi military officers were routinely sent to Ft McClellan in the United States during the 1960s to learn more about chemical-biological warfare. A small group of about nine scientists was recruited to begin working on covert biological research. These professionals were chosen from several different disciplines and drawn from several ministries, including Higher Education, Defense, and Health. The common denominator among the first generation of Iraqi chem-bio weapons scientists was that they were selected for their qualifications and were among the most promising scientists of their generation during the 1970s. Several of these scientists were sent abroad for additional advanced training. For example, Dr Rihab Rashid Taha, a plant scientist and former Iraqi BW scientist, was sent to Great Britain for an advanced degree. Later Dr. Muzhir (Muder Moder) Al Falluji, a lead biologist, was also sent abroad. Over time, political considerations entered into the selection process. Thus, by the mid-1980s, recruits were chosen more for their loyalty to the regime rather than for their technical skills or as junior scientists capable of making major breakthroughs in research and development. The Iraqi scientists increasingly relied upon a mentor system within highly compartmentalized clusters. By the 1990s as politics became an even more important criteria for the Iraqi program, many of the senior scientists who played large leadership roles were foreigners who had been recruited from neighboring countries.[3]

Another shared characteristic of Iraq's early clandestine research, when compared to several other early covert programs in the developing world, was that chemical and biological research efforts were often combined, especially during the early years. After a few years more specialized dedicated labs were built at Al Hasan in the suburbs of Baghdad and at Ibn-Sina Center.[4] By the late 1970s the first Iraqi chem-bio program had failed to produce any significant results. One reason cited by investigators who examined why Al Hasan failed to produce any significant output was extensive fraud by several of the senior managers of the program. In response to this investigation, the government parceled out the staff and facilities to several different agencies from late 1979 through 1985. According to the Duelfer report, the best scientists went to the Iraqi Intelligence Service (ISS). The ISS played a key supervisory role in overseeing covert biological weapons activities until the overthrow of the Saddam Hussein regime in 2003.[5]

The Iraqi early pattern of developing a covert chem-bio program is remarkably similar to several other known programs in the developing world. In many countries early efforts to start a chemical and biological initiative have been located within the same government sponsored initiative, and often within the same building. The senior management head of covert biological weapons programs have more latitude than their counterparts running covert nuclear programs. Finally, several past covert biological research programs have also been characterized by widespread fraud by senior program managers.

At least this was the case in South Africa where a close friend of the Defense Minister's nephew, Dr. Wouter Basson, was chosen to lead the secret chem-bio program called Project Coast that was housed in the South African Military Service (SAMS). It took a few years before specialized front companies for chemical and biological weapons research were developed. The loose oversight by senior political officials is widely cited as the reason why Dr. Basson and several of his senior managers were alleged to have engaged in extensive fraud and personal profiteering when Project Coast front companies were privatized.[6] In both cases, loose oversight by political officials and the lack of standard independent accounting procedures seemed to encourage corruption that helped to derail weaponization. These similarities suggest that such factors as personal graft and corruption among the scientific or political elite who are responsible for managing covert weapons programs in many developing countries may serve as a constraint on developing highly effective biological weapons.

A comparison of the types of scientists selected to work for Iraqi and South African biological weapons programs highlights the fact that there are likely to be significant differences and changes in the academic credentials and advanced training patterns of the scientists recruited to work for a covert biological weapons program in the developing world over time. As noted above, members of the first generation of Iraqi biological weapons scientists were drawn from a variety of academic specialties. What they shared with members of the first generation of BW scientists in several other countries is that as a group they represented some of the "best and brightest" of their generation. Many members of the first generation of weapons scientists from several countries in the developing world also traveled abroad to the United States and Western Europe for training courses and advanced education. However, in several cases access to education in the west became increasingly difficult to complete by the end of the 1980s.

A similar pattern of increased isolation from the west developed in South Africa over time as well. In the early years, South Africa military officers also routinely went to the United Kingdom and the United States for special training in chem-bio programs. However, by the late 1970s the United States, along with the United Nations, imposed sanctions that made it increasingly difficult over time for South African weapons scientists to enter the United States or European countries for studies or research visits. Many members of the first generation of scientists recruited to work for Project Coast were also drawn from a variety of fields. A large number of the scientists were veterinarians. Disproportionate numbers of veterinarians were recruited in the case of South Africa because members of this professional at the time were extremely well-trained, having earned advanced degrees in at least two different fields of science.[7] Others scientists were trained as chemists or human medical doctors. A large number of this first generation received one or more of their degrees in the United Kingdom, Germany, or other European countries.[8] By the time Project Coast got under way in the late 1970s, South Africa was already an isolated state. One important recruitment tool used by Project Coast managers was the opportunity to have much greater access to the scientific literature than was possible for most South African scientific researchers at the time.[9] As a diplomatically isolated state, South Africa, much like the Iraqi government in the latter years of the program, also sought to use the expertise of outside experts in addition to national scientists.[10]

The diversity of academic backgrounds and varying expertise of biological weapons scientists in the two countries should cause analysts to pause before making sweeping generalizations about the type of scientific background required to work on covert weapons programs. The fact that many Project Coast scientists were veterinarians, while at least one of the better-known Iraqi scientists was a plant scientist, suggests how hard it may be in the future to identify nascent biological weapons programs hidden in dual-use civilian facilities.

The adjustments made in both countries due in part to increased external pressures and growing isolation, suggests further that patterns evident in the past programs may not be replicated in future ones. This is particularly true in the current era where the knowledge needed to develop biological weapons is becoming widespread throughout the world. A question that is increasingly being asked in western analytical circles, and one that is covered in more detail in the next section, is whether current and future scientists recruited to work for national covert biological weapons programs or for terrorist groups, will necessarily obtain their advanced education and training in the West. Extensive anecdotal and some aggregate data discussed in the next section, suggest an important new trend may be in progress whereby many of tomorrow's generations of biological weapon scientists will be trained in non-western institutions in Asia, Latin America, and Africa. In an era of rapid globalization, due to rising costs of education, and most importantly to heightened concerns about terrorism in the West, more foreign students, particularly those from Middle East countries, seem to be looking at alternative venues for education in the life and physical sciences.

Policy Lesson #2: Initial covert biological weapons research and development efforts tend to focus on readily available naturally occurring pathogens.

Another interesting aspect of the first program in the 1970s and the restarted covert biowarfare programs in Iraq during 1985 until the first Gulf War was the fact that Iraqi scientists explored the feasibility of using naturally occurring pathogens. Iraqi scientists in their initial efforts, and again in the 1980s, studied fungal toxins, including trichothecene, mycotoxins, and later aflatoxins. A variety of bacteria, toxins, and viruses, including "clostridium botulinum, spores of bacillus anthracis, cholera, polio and influenza virus, were involved in the restarted program in the early 1980." Several Iraqi researchers involved in both phases told American investigators that "botulinum toxin and anthrax were the backbone of the Iraqi pre-1991 BW program" restarted in early 1980s.[11]

Prior to the first Gulf War, several scientists worked on both human and animal viruses, i.e. influenza and polio, to determine their usefulness as BW agents. The polio virus program appears to have been closed in 1979 while work on other viruses continued. One US-trained veterinarian, Dr Muzhir Al Falluji, reportedly also experimented with animal orthopox viruses. Work on weaponized ricin, at least in a limited fashion, was pursued in the 1980s and again prior to the first Gulf war. This research followed earlier work on possible use of wheat as a weapon. During the 1980s there were several projects, including one sponsored by the Intelligence Services. These projects allegedly use human testing but this accusation has not been substantiated. There was a collaboration among personnel at Al Salman and the military to field test 155 mm shells as a delivery device for warheads loaded with ricin at the end of 1990 and possibly also after 1992. The Al'Aziziyah farms supplied the Al Tariq Facility with castor beans. Many farmers, scientists, and engineers familiar with this project told investigators after the 2003 war that efforts were made to weaponize the castor beans. Other staff members continued to maintain that the castor beans were processed for use as brake fluid and for tire production. Other research appeared to examine the properties of castor oil as an anti-foaming agent in the yeast industry and for pharmaceutical-related research. A shipment of caster beans for a university remains unexplained. However, Dr. Al Azmirlic, a former Iraqi Intelligence Officer and the scientific advisor to Saddam between 1992 and 1996, said that ricin produced at Al Shameir Hospital in Al Rashad was than transferred to Al Kaham where it was developed into a stable liquid to deliver as aerosol in small rockets, cluster bombs, and smoke generators. After the first Gulf War, Iraqi scientists were able to restart work on Brucella at the College of Science using an isolate from a patient at the Ibn-al-Khatib Hospital. This project was coordinated through the Ministry of Health. During the project, Brucella was isolated and grown. The researchers extracted and purified the endotoxin, tested it on mice, and determined that the toxin was not as effective as Shigaq toxin, ricin, or botulinum.[12]

The Iraqi efforts to restart their biological weapons program by using natural pathogens are important because these examples provide vivid support for the prediction that both national covert scientists and terrorist are likely to use readily available, naturally occurring pathogens as weapons in their initial attempts to develop biological weapons.[13] At least this was the prediction of the majority of 43 scientists and researchers interviewed in South Africa during 2003. The overwhelming majority of these researchers predicted that the most likely bioagent that would be used by national researchers or by terrorists living in the developing world would be readily available, naturally occurring pathogens.[14] In recent years, several researchers have also noted that hundreds of different types of fungi found on the diverse plants and trees in rainfall areas and other rural areas throughout the world could be easily processed to form new biowarfare pathogens.[15] While few scholars in the social sciences have spent time analyzing the nature of the threat arising from a host of naturally occurring pathogens, more government officials have become aware that secret national or terrorist efforts to engage in biological warfare in the future is likely to rely upon natural pathogens. To try to counter this emerging threat, participants at the most recent Review Conference of the Austria Group that was held in June 2004 agreed to add five plant pathogens to the control list. This was the first time that plant pathogens had been added to the restricted control list since 1993.[16]

Policy Lesson #3: Many developing countries and terrorist groups are more likely to use crude or novel delivery devices to deliver biological weapons designed to function as "weapons of mass disruption" or "weapons of terror" rather than "weapons of mass destruction."

In recent years there has been an increased concern about the possibility of agro-terrorism attacks in the United States. Much less attention to date has focused on the strategic implications of the fact that leaders, scientists, and terrorists in the developing world are likely to use biological weapons for mass disruption and as "weapons of terror" rather than "weapons of mass destruction." One reason for the lack of attention to the use of biological agents as weapons of terror or mass disruption may be due to the fact that many strategic analysts are still wedded to a model of weaponization that is based on the covert, large-scale weaponization efforts of the former Soviet Union's secret biowarfare program.[17] This paradigm assumes that national covert programs will only pose a threat if they succeed in producing and weaponizing large amounts of weaponized biological agents that can be delivered using sophisticated and highly reliable missiles or planes in order to produce mass destruction. However, a growing body of evidence suggests that secret military programs and efforts by terrorist groups, especially those located in the developing world, are likely to be smaller scale efforts intent on using biological agents as "agents of mass disruption."[18]

The strategic logic of Iraqi military commanders during Saddam Hussein's regime adds some additional confirmatory evidence for the hypothesis that biological weapons are most likely to be used as weapons of terror rather than mass destruction by politicians and military decision makers in the developing world. The outbreak of the Iran-Iraqi war in the late 1980s provided a major impetus for Iraq to develop biological and chemical weapons that could be used against their long-time enemy. Iraqi scientists told both UNSCOM and US investigators in the 1990s, and again in 2003, that a crash effort was undertaken to develop nuclear, chemical, and biological weapons that could be used against their arch enemy, the fundamentalist Shi'a Islamists. According to Rolf Ekeus,

> The leadership in Baghdad had seen this war as a reflection of Iraq's strategic role as a gatekeeper for the Arab nation against a Persian penetration westwards into Arab territory. The wealthy, but military weak, Sunni-ruled Gulf States from Saudi Arabia to Oman were considered easy prey for a militant Iran. During the eight years of war, Baghdad had learned that Iran, with nearly three times Iraq's population, was a formidable enemy that could only be matched with resort to chemical weapons. Iraq had concluded that its self-appointed role as protector of the Gulf Arabs required WMD to compensate for numerical inferiority.[19]

More recent statements made to Americans investigators since the United States invasion in 2003 sheds even more light on the Iraqi strategic views about the utility of biological weapons. These recent investigations confirmed that Saddam Hussein wanted to use biological weapons. After the outbreak of Iran-Iraq war in 1980 a reinvigorated effort was made to develop biological weapons that could be "put in a bomb."[20] According to statements made to American investigators, "Saddam envisaged all-out use…in a plan to strike Israeli cities he specified that the 'many years' agents, presumably anthrax spores, were to be employed against his foes." Even more ominously, Brig. Dr. Mahmud Farraj Bilal Al Samarra'I claimed that "if the Iran war lasted beyond 1988, Saddam would have used BW." [21]

Despite these statements of intensions, there was a serious gap between these goal statements and Iraq's technological capabilities. Consequently, at the end of the 1980s as Iraq faced costly setbacks and the possibility of defeat, military leaders developed specific plans to use biological-filled projectiles, along with chemical shells and bombs, if the conflict had continued much longer. Iraqi military commanders were well aware of the weaknesses of biological agent-filled bombs and shells and the fact that many of the weapons were likely to malfunction. However, Iraqi commanders went ahead and planned to use this class of weapon, if authorized by political authorities, during the Iran-Iraq war as a "weapon of terror." The planned delivery device for the biological-filled bombs was to be the Al Hussein missiles, along with several other devices. By 1990, other facilities were manufacturing additional types of delivery devices for BW agents including bombs, warheads, and aircraft auxiliary fuel tanks. Military planners continued to refine their future plans to use biological weapons even though there were continuing technical shortcomings with using either the Al Hussein missile or R-400 artillery shells to deliver BW agents. Lt General Hazim, Commander of the Surface-to Surface Missile Force, explained the strategic logic behind using biological weapons by noting that "an Al Hussein with a BW agent filled warhead, would fulfill its purpose, if after impact in an enemy country sufficient material survived to enable its detection as BW agent. It was a weapon of terror."[22]

Lt. General Hazim's statement is important for underscoring the fact that field commanders treated these reserve weapons as a weapon of terror rather than weapons of mass destruction. The Iraqi program was patterned after the former Soviet model of weaponization and had a similar goal of large-scale production and use of sophisticated missiles armed with biological weapons of mass destruction. However, when the time came to contemplate actual use, technical deficiencies did not prevent the Iraqi military from contemplating the use of biological bombs as weapons of mass terror. Unfortunately, the high probability that nation-states in the developing world, along with terrorist groups, are most likely to pursue biological weapons for the purpose of terror and mass disruption rather than mass destruction remains a minority view in the west. The way Iraq contemplated using biological bombs should help sensitize analysts to the fact that biological agents are most likely to be used as weapons of mass disruption or terror rather than mass destruction in the developing world.

One Western analyst who has written extensively on the subject is Mark Wheelis, who concisely outlined several differences between developed and developing societies that make agric-biowarfare and humans or animals as delivery systems much more attractive as disruptive biological weapons in the developing world. According to Wheelis, natural biological pathogens and simple delivery devices (i.e., a single infected person) can be a likely disruptive force within a population already weakened by malnutrition or other diseases. A few cows infected with a highly infectious agent such as foot-and-mouth disease at an agricultural auction can quickly wreck havoc in a monoeconomy. Such attacks require only minimal expertise to develop or deliver and can be easily introduced in a highly covert manner.[23]

Policy Lesson #4: **Open source literature will be used for covert BW research.**

Iraqi scientists working on a reorganized covert biological weapons program in the 1980s told American debriefers that they used open source research literature to help restart the program. Dr. Rihab, who was appointed as the new technical head for the second effort to develop biological weapons in Iraq, formed a team to conduct literature surveys as the first step in a five-year plan to weaponize biological agents. Initially, this search included searching indices of the Stockholm International Peace Research Institute (SIPRI).[24] Dr. Rihab's approach to reconstructing the Iraqi program during a five-year plan underscores the dilemma currently being debated by scientists within several disciplines and government officials about how best to balance the requisite need for scientists to publish and exchange research results and ideas with the need of national security. In a highly globalized world it seems nearly impossible to stop the flow of scientific research results or strategic writings. Two recent examples illustrate the current dilemma. The first example pertains to the fact that most of the ideas in Wheelis article cited above are also contained (in a near verbatim format) in an article written by Ijaz Ahmad Rao entitled "Importance of Defensive Biological Weapons in Agro-terrorism." This article is posted on an open web site (www.Pakistan.com).

The second example pertains to a research report authored by Richard Guthrie, a researcher working for the same research organization used by Iraqi scientists decades ago; SIPRI. Richard Guthrie's report discusses how developments in mapping the human genome, which could lead to improved medicines and vaccines for heart and neurological problems, could also be used by terrorists. He notes that "the free access to genetic sequence data for the human genome and a large number of other genomes, including for pathogenic micro-organisms, is a great scientific resource, but it could pose a significant threat if misused." While warning that "biotechnology research, particularly concerning human genes, could lead to the development of a new class of biological weapons," he also noted that as yet, no plausible threats that have been made.[25] While many other examples could be illustrated, these two recent examples illustrate how scientific and strategic ideas related to biological or strategic ideas that were once published in peer reviewed journals and read primarily by a specialized audience are now widely available and disseminated through the internet to much wider audiences.

Policy Lesson #5: Covert biological weapons research and development will increasingly occur at multiple dual-use civilian facilities that will increasingly use mobile equipment and production facilities.

By 1990, Iraq's second attempt to develop secret production facilities at several dual-use sites had succeeded. These dual facilities included the Foot and Mouth Disease Vaccine plant (FMDV) at Al Dawrah. Here production facilities were also adapted for the production of botulinum toxin and maybe also anthrax. Some reports claimed that mobile storage containers for anthrax were also developed during this period. Research and development activities focused on studying the feasibility of using a variety of pathological agents as weapons including hemorrhagic conjunctivis, human rotavirus, and camel pox.[26]

During this period, Dr. Taja was reported to have turned down proposals to develop mobile labs. However, several UN and US weapons inspectors continued to collect reports of such facilities having been developed.[27] When and to what extent Iraq developed mobile weapons production facilities continues as a controversial subject that is shrouded with conflicting claims. Much of the evidence remains classified. However, there were unsubstantiated reports in several US newspapers that Iraqi biological weapons equipment, including entire laboratory facilities, may have been moved to neighboring countries. What is not in doubt is the fact the two mobile labs that were initially claimed to be mobile BW labs by the Bush administration in the wake of the second Gulf War were quickly diagnosed by a group of experts from various US government agencies as being mobile hydrogen weather balloon laboratories.[28] Regardless, it is clear is that after the first Gulf War and the introduction of UN weapons inspectors, Iraqi scientists became much more interested in using smaller, more mobile pieces of equipment. Partly as a result of the vigorous challenge inspections and subsequent destruction of proscribed facilities by the UNSCOM weapons inspection team prior to their forced departure in 1998, the amount of BW material retained by the Iraqi government by the end of the 1990s was extremely small. Scott Ritter, a former inspector, estimated the size of the former Iraqi bw program thusly:

> All of Iraq's retained BW material could be carried in fewer than ten thirty-five ton trucks, and three to five semi-trailers. They could be stored mounted in their vehicles, inside a warehouse, or buried underground. The supporting documents for this program could be easily kept in a single sedan-size vehicle.[29]

What was developed in the years between the last UN weapon inspectors and the US-led investigations after the war is likely to remain the subject of some controversy. Part of the controversy centers around the question of what, if any, mobile facilities were developed by Iraqi scientists. One of the more interesting insights documented in the

Duelfer report was the fact that Iraqi scientists nearly 15 years ago seriously contemplated developing mobile facilities. What is not widely appreciated is that a great deal of progress has been made during the subsequent 15 years in reducing the size and cost of equipment needed for both civilian and backroom biowarfare research. Recent studies have documented that the cost to set up an urban lab in a garage or "in the bush" is much lower today than many analysts assume.[30] There have also been several advances in biotechnology equipment that have been fueled primarily by economic demand and the resurgence of highly infectious diseases. For example, recent work in biopesticide processes comparing the quality of fungal spores manufactured in sterile and non-sterile fermenters found no difference in the quality of the product. These findings suggest that it may be cost-effective and feasible to use non-sterile equipment in certain botechnology applications in the future.[31]

Another illustration of how mobile equipment has become occurred in South Africa in 2003. In 2003, a visiting Danish researcher and two South Africans surprised much of the scientific establishment, the government, and the public with their announcement that they had "cloned a cow" at a relative remote research station using a new, handmade cloning method that used a hand-crancked generator for power. [32] This small-scale collaboration, based on personal links established by individual researchers in South Africa and one or a few researchers in other countries, is the most typical pattern of collaboration in South Africa biological and biotechnology research.[33] Similar small group international collaborations are also found throughout Africa and other parts of the developing world. The methodology used to clone the first cow in South Africa is so simple and cheap that it may signal a new era of affordable cloning for researchers in developing countries. The technique, called "homemade cloning," to create genetically identical copies of animals is much cheaper and simpler than existing methods. According to Michael Bishop, ex-president of Infigen, a cattle-cloning company in Wisconsin, "It's a huge step towards roboticising the whole process." The inventors of the new technique claim that personnel can be quickly trained to use the method. Currently, researchers are exploring the feasibility of using the technique to clone endangered species.[34]

While cloning is a relatively simple process that does not require a sterile or negative pressurized environment, research and development involving many viruses do require the use of a Bio-science Level Three (BSL-3) laboratory facility. Work with the most serious viruses, i.e. infectious diseases that are transmitted via the air and for which there is no known cure, require a BSL-4 laboratory. Equipment requirements such as the need for hoods, sterile research environmental conditions, and negative pressure work areas have long been thought to be one constraint for scientists working in poor countries or for terrorists. However, advances in the development of modular mobile laboratories that can be set up within hours in even remote locations suggests that the equipment and facility requirements that may have served as one type of constraint may not function as a barrier much longer. Although the current demand for such facilities is limited to organizations such as the Center for Disease Control, the demand for mobile laboratories is likely to become an increasingly global market in the future.[35]

Key actors involved in strengthening the weapons of mass destruction regime have attempted in recent years to slow down the spread of smaller and more mobile pieces of equipment that have serious biological proliferation implications around the world. At the June 2002 Review Conference of the Austria Group, an agreement was reached to lower the volume for fomenters on control lists from 100 liters to 20 liters. Participants at this same meeting also approved regulations for the export of machines that could be used to produce biological weapons.[36] Export restrictions cannot stop a determined deviant from obtaining newly prescribed biotechnology equipment because of the strength of growing demand for civilian biotechnology applications. At the same time that the cost, size, and energy demands of civilian biotechnology facilities is lessening, the demand for such equipment and facilities is growing as more private companies and state-run programs seek to take advantage of advances in civilian biotechnology research and development. Thus, the number and nature of dual-use biotechnology facilities and equipment that may constitute proliferation threats are also increasing.

Policy Lesson #6: Covert biological warfare research and production programs housed in dual-use facilities are difficult to detect, but full-scale production activities are difficult to hide.

According to post-2003 reports, Iraqi scientists had produced large quantities of anthrax, botulinum toxin, clostridium perfringens, afatoxin, and small quantities of ricin, and had more than 180 BW weapons deployed to five hidden sites by the early 1990s."[37] Then Desert Storm destroyed most delivery devices, including missiles and sprayers. Sadam Hussein ordered stocks hidden and work continued at dual-use facilities so that Iraq would be able to resurrect and restart the biological program quickly after UN weapons inspectors had left. UN weapon inspectors stayed for nearly seven years. During this period much of the rest of the stock of BW agents and delivery devices was destroyed by persistent UN inspectors. However, allied intelligence during and immediately after the war missed the largest Iraqi biological weapons plant at Al Hakam. Instead of declaring the country's biological warfare capabilities after the Gulf War, Iraqi government officials and scientists focused on maintaining and expanding dual-use industrial production capabilities at Al Hakam and other facilities.

By the mid-1990s continuous intrusive UN weapons inspections and the pain caused by comprehensive sanctions convinced Saddam Hussein that the Iraqi regime should get rid of hidden biological weapons and seed stock. The Iraqi government's goal shifted to secretly retaining as much of the Iraqi biological weapons infrastructure as was possible in order to be in a position to resume biowarfare research and development once the sanctions were lifted and the UNSCOM inspectors were gone.[38]

From 1992 until 1994 Iraq managed to expand their capabilities of dual-use facilities at the Al Hakam facility without being detected by UN weapons inspectors. After the UNSCOM inspectors completed their first visit to Al Hakam in 1991, managers at the facility were able to acquire a 1,500 liter fermentor and a dryer from another installation.[39] The cover story used to explain the expansion of activities at Al Hakam was that the facility was working on single-cell protein and biopesticide research.[40] Both the electricity and water utilities at the plant had to be expanded so that the capabilities "fit" the cover story that the plant was used to product biopesticide, called Al Nasr or "Victory," and to conduct research on Single Cell Protein (SCP) as alternative to feedstock.

Throughout the 1990s, the Iraqi covert research and development program was able to develop sophisticated, genetically modified organisms and some novel processes and procedures. At the Al Hakam plant, the post-war dual-use research led by Dr. Al Ma'dhihi developed a novel and cheap domestic solution to Iraq's need for BW growth media by using waste products from food and agricultural processes. This cheap bacterial growth medium could be used for Bt or for anthrax production. At one point the biopesticide formulations produced at Al Hakam in the 1990s had to be stopped and the formulation changed to meet the complaints of farmers about the dry Bt product called Al ANasr or "Victory" being supplied from Al Hakan. The biopesticide was supposed to be sprinkled onto plants but the farmers had difficulty using it because the pesticide quickly aerosolized into a cloud and didn't form an adequate residue on the plants.[41] Extensive efforts went into improving the dry agent formulation for agricultural applications. Work on other organisms also progressed, including modeling work with anthrax.

Policy Lesson #7: No single control strategy is effective in stopping covert biological research and development, but a combined approach backed by a strong international consensus can disrupt or slow down the research and development process and substantially raise the cost of conducting covert BW research and development.

The recently released Inspector's General Report to the CIA confirms the earlier assessments of UNSCOM inspectors that the Iraqi biological program had largely been destroyed and hidden stocks degraded by the time the inspectors were asked to leave in 1998. No single control strategy—war, comprehensive sanctions, intrusive weapons inspection, or export controls—was completely adequate for stopping covert biowarfare research and development at civilian biotechnology facilities. However, the combined use of these control policies, backed up by an international consensus on the importance of maintaining checks on the Iraqi regime, worked remarkably well until the international consensus deteriorated and the nature of the sanctions was modified in the mid-1990s.

Over time the prolonged comprehensive sanctions plus the aggressive on-site inspections of the UNSCOM teams raised the cost of maintaining covert biological weapons research so much that in 1995

Saddam Hussein approved a decision to abandon existing secret biological programs at such facilities as Al Hakam while continuing secret covert research and development at new secret labs run by the Iraqi Intelligence Service. Defectors told both UNSCOM and US weapon inspectors that Saddam and his advisers were surprised by how vigorous the inspections were during the early 1990s. Saddam Hussein was reported to have also been concerned about the adverse effects that discovery of his secret BW program might have on his goals of getting rid of UNSCOM inspection teams. By the mid-1990s, the effects of comprehensive sanctions had taken a huge toll on Iraqi commerce and the quality of life of Iraqis, and a priority goal of the Saddam Hussein regime was to obtain relief from the comprehensive sanctions.

In hindsight, the combined effects of challenge inspections that destroyed prescribed materials and placed suspect sites under UN supervision by inspectors on the ground backed by comprehensive sanctions, and periodic bombings in the northern and southern "no-fly zones," proved to be an effective but costly strategy for preventing Saddam Hussein from resurrecting his nuclear, chemical, or biological programs. While covert biological research and development activities did continue, the scale of the efforts was very small and designed to maintain existing expertise and facilities rather than engage in full-scale production.

This comprehensive control strategy required a strong global consensus and the support of both the United Nations and important nation-states in the West and Middle East in bilateral and multilateral dealings with the Hussein regime. However, after 1995 the international consensus eroded as the pain of sanctions contributed to a rise in the infant mortality and lower life expectancy of Iraqis. In place of the comprehensive control strategy, a series of stop-gap diplomatic measures were periodically introduced that were designed to prevent the status quo from collapsing. Seeing the erosion of support within the international community, Saddam continued to challenge the scope of the inspectors mandate and to demand relief from the sanctions. The result was a series of crises and stand-offs on the ground between Iraqi forces and weapons inspectors that culminated in UN inspectors being kicked out of Iraq. The fact that neither the United States nor the UN challenged Hussein's decision to expel inspectors beyond a stepped up bombing campaign within the no-fly zones signaled an important dilution of the control regime. After 1998, it proved nearly impossible to obtain a clear intelligence picture of what type of R&D activities were occurring in Iraq. Similarly, the Food-for-Peace program implemented by the UN signaled another important change in the control regime. After changes were made to the international sanctions, Saddam had a steady source of money from oil sales that he used for other purposes, including covert WMD research.[42]

While export controls stopped some efforts to obtain equipment, materials, and expertise from abroad, there are other instances where export controls failed to stop efforts to import equipment and supplies into Iraq. An important example of where export controls worked occurred in 1995. Iraq attempted to purchase two turnkey 50 cubic meter fermentor plants from a Russian Company. However, the deal fell through because the company did not receive an export license.[43] In contrast, Iraq was able to make improvements to nitric acid paint at al-Qa Qa' with equipment, materials, and expertise obtain from Russia, Yugoslavia, Belarus, and Ukraine as recently as 2002.[44]

Throughout the 1990s as Iraq expanded its civilian biotech facilities to provide a more credible cover story, the regime pursued several different strategies in order to obtain needed equipment and supplies for dual-use production. As noted above, some of the equipment was successfully imported from companies in Europe and other parts of the world. The Al Hakam plant was able to obtain small, five cubic meter fermentation vessels from foreign suppliers. Several of the foreign suppliers for Iraq's civilian biotechnology front companies included some of the largest and best known firms involved in supply biotechnology equipment and supplies, such as the Italian company Olas and the Swiss firm Chemap.[45] The managers at the Al Hakam plant also borrowed equipment from an Iraqi veterinary vaccine plant. Local fabricators were also employed to modify the spray dryers at Al Hakam.

While Iraqi officials were successful for several years in hiding covert activities at the Al Hakam plant, the continuous challenge inspections and intelligence gathering activities of the UNSCOM inspectors eventually were successful and the inspectors became aware of the activities at Al Hakam and other sites. The many popular accounts that claim that the international community only learned about Iraq's secret biological warfare program after Hussein's son-in-law defected are incorrect. Instead, the inspectors had presented the regime with evidence of violations of proscribed activities at Al Hakam, and UNSCOM and the Iraqi regime were working on a Full, Final and Complete Disclosure at the time that Hussein's Kamil, Hussein's son-in-law, defected.[46] In fact, the sequence of events suggests that the inspection activities may have triggered Kamil's defection.

This is an important point as it appears that the dual-use capabilities at Al Hakam were discovered by "good intelligence" on the ground backed up by painful sanctions and export controls. In 1995 UN inspectors confronted Iraq with evidence that the country was importing excessive quantities of bacterial growth media given the limited biotech industrial capacity at Al Hakam and other sites. Iraqi officials acknowledged that they had used the imported materials to produce two biological agents. UN and Iraqi officials drafted a Full, Final and Complete Disclosure that detailed these activities. Sadam's son-in-law, Hussein Kamil's defected only two weeks before the disclosures were made public. Kamil's revelations filled in additional details and probably hastened the destruction of Al Hakam and several other dual-use capabilities. In June 1996, Al Hakam was destroyed and the FMDV was disabled. Thus, the dual-use capabilities at Al Hakam were discovered by "good intelligence," the difficulties imposed by comprehensive sanctions, all backed up by a strong international consensus.

Policy Lesson #8: Biological weapons inspections are difficult to conduct after a war. Controlling the scientists and technicians who retain biological weapons knowledge for the rest of their lives is one of the more difficult proliferation tasks to "solve."

Since the US-led Iraqi Freedom Campaign, many of the research scientists and technicians who worked on the secret biowarfare program have been debriefed, and former suspected WMD sites identified by UNSCOM revisited by US weapon inspectors. The most recent round of investigations reconfirmed that prior to the war in 2003, Hussein's biological program had been destroyed except for a very small amount of research designed to allow scientists to retain their skills. The world also learned (again) the difficult lesson that it is nearly impossible to control the research scientists and technicians who worked on the covert biowarfare program.

The fact the Iraqis secretly and unilaterally dismantled and destroyed much of their biological materials and related documentation during the 1990s left lots of questions unanswered, and residual uncertainties persists. The extensive amount of damage at known or suspected sites during the war destroyed additional evidence as did widespread looting immediately after the war. American investigators also found a widespread tendency among captured Iraqi scientists to "blame the dead guy" for key covert weapons development.[47] There remain a number of unanswered questions. One of the most vexing issues is the questions of whether Iraq developed mobile biowarfare production capabilities and if so, where are these resources today? Another unknown is what research and development was conducted at the newer secret Iraqi Intelligence laboratories that were built outside of Baghdad after the first Gulf War.[48] Answers to these questions may never be obtained, and residual uncertainties will no doubt fuel stories about covert biological activities in neighboring countries and inside Iraq for years to come.

SOME CONTEMPORARY ISSUES IN THE DEVELOPED AND DEVELOPING WORLDS

While Iraq's former biowarfare program is useful for illustrating some aspects of past covert national biological weapons programs, there is more interest and concern in the United States and Europe about issues more closely related to homeland security since September 11, 2001 and the anthrax letter attacks the following month. This section highlights three issues that may affect biotechnology research and development in the United States and some trends in the spread of global biotechnology throughout the world. To date, little attention has been paid to the proliferation implications of the globalization of civilian biotechnology in the national security literature. An important reason why in the United States is because analyst are now more focused on homeland security issues. These two sets of issues may be totally unconnected; however, perceptions of important issues differ so widely between and among analysts in the developed and developing world that the issues covered in this section are often presented as distinct types of contemporary biosecurity issues.

US Contemporary Controversial Issue #1: How to, and who should, control the publication and the dissemination of biological peer review research possible biowarfare implications?

Since the end of the Cold War much of the nonproliferation efforts of the US government in bio-defense has focused on preventing the external proliferation of technology and expertise from the former Soviet military-industrial complex. Much less attention until recently has focused on developing countries. In the past couple of years there has been some recognition among national security analyts that several countries throughout the developing world, such as Brazil, Cuba, India, Malaysia, Taiwan, and South Africa, who have relatively small but sophisticated first-world industrial sectors, are also capable of producing world-class, dual-use chemical and bio-technology products. The lack of evidence that Iraq did in fact restart a covert biowarfare program in 2003 has only served to underscore even more dramatically how difficult it is likely to be in the future to identify potential BW proliferation risks hidden in civilian biotechnology facilities.

Several middle-level countries throughout the developing world remain likely candidates for covert biological weapons programs since they developed covert weapons, including biological warfare weapons, in their recent past. In addition to more familiar covert weapons proliferation concerns, new concerns have emerged recently about the possibility that non-state actors, i.e., terrorist groups of different ideological persuasions and individuals with access to modern laboratory facilities, may soon develop biological pathogens as weapons from either naturally occurring pathogens or through sophisticated new genetically modified organisms.

Recent concerns about emerging threats in the developing world have now merged with longer standing concerns within the western scientific community about the possible misuse of medical experiments and basic research experiments in genetics and biochemistry. The work of a group of animal researchers in Australia a few years ago caused alarm bells to go off when their experiments succeeded in finding a way to eradiate wild mice by bioengineering a more virulent strain of ectromelia virus (mousepox).

The genetically modified strain killed 60 percent of wild mice. Even more disturbing was the fact that the genetically modified strain also killed large numbers of mice who had been vaccinated and were resistant to the parent virus and a more virulent strand. The Australian researchers, aware of the biowarfare implications from this line of research that used relatively simple genetic modification techniques, were concerned about the possibility that their research would serve as a blueprint for terrorists seeking to develop a new strain of pox virus. After consulting peers in Pest Animal Control Cooperative Research at the Australian National University in Canberra, the researchers submitted their research results for publications to the prestigious *Journal of Virology*. The editors of the *Journal of Virology*, while also concerned about the national security threats inherent in the line of research, published the results without modification after consulting with peer reviewers. The journal really had no other choice since the research article would have been published by an Australian or European journal if the editors of the prestigious American publication had rejected the article.[49]

This experiment is only one of several recent examples of experimental research that results from the creation of organisms or knowledge with "dual-use" potential.[50] Even before the mousepox experiments, concerns were being raised about the possible misuse of biological research. The National Academy of Science report, widely referred to as the Fink report and completed during the fall of 2003, raised the profile of national security concerns by calling for greater participation by experts who are more familiar with national security concerns on peer review boards. The National Academy of Science report stimulated additional studies by government and private organizations that have focused on ways to better manage the national security implications of biological research to find ways to better manage dual-use scientific research.[51] One major outstanding issue is who should decide which research results get published and which ones do not. A related issue is the question of whether a national security review process should be voluntary or compulsory and run by scientists or government bureaucrats. The controversy generated to date suggests that it will not be easy to reach a consensus view on these issues that may impinge on the very essence of the scientific process and free speech.

On March 4, 2004, the Bush administration announced the creation of a new federal advisory board designed to help ensure that federally funded biological research does not aid bioterrorists. A 25-member National Science Advisory Board for Biosecurity will advise all federal departments and agencies that conduct or fund research that could be used by biological terrorists on how best to prevent that from happening. At the time of the announcement, Tommy Thompson, the Health and Human Services Secretary, noted that, "Sadly, the very same tools developed to better the health and condition of humankind can be used for its destruction" in announcing board's creations…for the health and security of our nation, we must take the needed steps to improve biosecurity measures for this type of research."[52] While the creation of the board implements one recommendation made in the October National Academy of Science report to keep genetically engineered viruses and other works from being used for bioterrorism, it ‘s mandate does not cover privately funded biotechnology research in the United States nor public or private research efforts in other countries. A host of related issues related to how to regulate the dissemination and publication of biotechnology research in medicine and several other fields promise to be a highly controversial and vexing set of problems in the United States and other developed countries. If fact, most of the microbiologists and life scientists interviewed for this study cautioned that if not handled correctly, future efforts to regulate the dissemination of biological research funded by federal funds may affect the ability of United States to remain the premier center for scientific research and innovation in a host of commercial fields that use biotechnologies.[53]

US Contemporary Controversial Issue #2: New restrictions on select agents.

Several measures taken by the US government since September 11, 2001 have been designed to reduce the terrorist threat by increasing controls on special pathogens and foreign graduate students.[54] However, there are some preliminary signs that the new control measures carry with them some unintentional consequences.

At the time of September 11, 2001, the US government already had a number of restrictions on animal pathogens in place. Several foreign and animal pathogens were excluded from the United States by law and other pathogens that enter the country are covered by US Department of Agriculture regulations. Examples of restricted agents already in the United States prior to the 2001 attacks include Foot and Mouth virus, African Swine Fever Virus, Bovine Spongioform Encephalitis (BSE), Camel Pox Virus, and Newcastle Disease Virus.

Several additional restrictions have been added since 2001. The Patriot Act of 2001 provides the federal government with broad new powers to regulate the possession and handling of microorganisms and toxins. The Bioterrorism Preparedness Act of 2002 also contained new restrictions on handling microorganisms (i.e., viruses, bacteria, fungi, rickettsia) and toxins. The new statutory guidelines, along with earlier public health regulations, require researchers to register many more toxins as well as all individuals who possess deadly biological weapons agents and toxins. Individual researchers who work with these agents must now go through extensive screening procedures. The stricter security requirements for handling select agents and enhanced criminal and civil penalties also include fines of up to $500,000 for violating public health security regulations or federal laws. The current regulations are designed to counter lapses in earlier requirements that allow foreign nationals, including members of the Iraqi secret biological weapons program, and American dissidents to purchase dangerous pathogens through the mail from the American Type Culture Collection and from other locations.[55] The Public Health Security and Bioterrorism Preparedness Act of 2002 added new requirements for protecting sensitive information from public disclosure and new regulations for coordinating with other regulations and laws. These latter new requirements are among the most controversial of the new restrictions.

In the process of completing this research I visited a number of scientists in laboratories authorized to conduct research with "select agents." My original purpose was to obtain expert views about how best to monitor potential biological warfare threats from abroad. However, nearly all the scientists wanted to talk about the onerous burdens that the new laws and regulations placed on them and their laboratory staff. Many of these professionals were in the midst of doing surveys of all biological and chemical agents in their laboratories to ensure they were in compliance with new federal regulations and would not be subjected to legal violations carrying hefty financial penalties. I repeatedly heard horror stories about how many microbiologists and other researchers were thinking of abandoning their current research agendas due to the perceived onerous and intrusive reporting requirements now in place for those receiving federal money. For several of these scientists this type of shift would require abandoning a research program that they had worked on for years. Nevertheless, several researchers were thinking seriously about how to shift their research programs so they would no longer have to keep select agents in their laboratories.

US Contemporary Controversial Issue #3: Foreign graduate students.

Many of the same scientists also conveyed horror stories about how several of their current graduate students were unable to get their visas renewed. They also reported that foreign graduate students who were already accepted into the program were experiencing difficulties obtaining visas needed to enter the United States. In two instances, senior researchers were concerned about the fact that advanced graduate students who had returned to their home country for a vacation or the holidays were not allowed back into United States.

While aggregate statistics are not yet available to determine whether these anecdotes constitute a meaningful macro trend, these claims deserve to be monitored further since foreign students constitute such a large percentage of graduate students in many scientific fields in the United States. A decline in the number of foreigners choosing to come to the United States for their graduate studies would be a serious blow to the United States reputation as the leading country in attracting foreign students and a constraint to the ability of the country to maintain its premier position as a leading source of new biological discoveries and patents, and thus the economic competitiveness of our country. A steady decline in foreign students in the United States would also have economic implications. According to one recent study, international students contributed $13 billion to the US economy.[56]

Preliminary recent data indicates that there has been a sharp, short-term decline in the number of graduate students opting to come to the United States for graduate work in science and engineering in 2004. For example, one recent survey of 122 member institutions by the Council of Graduate Schools reported that the number of foreign graduate students enrolling for the first time at American universities in 2004 had decreased six percent for fall semester from the 2003 academic year. The fall semester enrollment declines weren't as steep as feared and were much smaller than the decline of 32 percent reported last spring.[57] However, any decline must be viewed as potentially very serious because American universities are so highly dependent on foreign students for teaching and research help, particularly in the sciences and in engineering. In these fields, foreigners typically comprise 50 percent or more of graduate enrollment. For example, the number of international student applicants at the University of Wisconsin (Wauwatosa) Medical College's Graduate School of Biomedical Sciences for the fall 2004 term is just half of what it was a year ago. The shrinking pool of international student applications is evident in many fields, but may be the greatest in scientific and technical fields where federal security officials have strong concerns about the wisdom of giving visas to foreign students. According to a member of the Wisconsin Technology

Council board, “Someone who wants to come into this country to study history will have less of a visa problem than someone who wants to go into engineering, computer science, math or especially the biomedical sciences, where you have concerns over bioterrorism and biohazards,”[58]

Most experts believe a major factor accounting for this recent decline is the difficulty, or the perceived difficulty, of getting student visas under tightened US immigration policies. Other factors include anti-Americanism abroad, and increasing competitiveness from universities in India, China and Europe.[59] To compensate and avoid continuing declines in enrollment in the future, many colleges and universities are starting to admit more foreign students. This year the State Department has tried to streamline the student visa application process. Most schools in the United States are also stepping up efforts to provide technical help for foreign students.

The recognition that the United States may be losing graduate students to other countries in the developed world, including Great Britain and Australia, is growing. However, there is much less recognition that countries throughout the world, including many in the developing world, are also working hard to recruit students from the same global pool of graduate students. For example, a study conducted in 2003 found that many foreign students studying in South African universities had chosen to obtain their degrees in South Africa rather than the United States or Europe due to cost and anti-terrorist policies.[60] This same study documented that in most science and engineering programs at South Africa’s major research universities and other colleges, foreign students in graduate programs comprise an even larger number of the student body than in the West. Many of these foreign graduate students are from neighboring countries in Africa and the Middle East. Just how significant this trend might be is not known as few western analysts have looked at this issue. The question of where graduate students in the sciences and engineering will opt to go for their studies in the future should be explored in future research. A very real possibility exists that if entrance restrictions in the US and into European Union countries persist, along with growing hostility towards students from Middle East countries, many more students in Asia, Africa, and Latin American, especially Muslims, may increasingly opt to study in research institutions outside the west.

Key Emerging Biosecurity Issues and Trends in the Developing World

Much of the attention in the United States related to biowarfare and bioterrorism has focused on research in human and animal health. Much less attention has been directed towards understanding the broader biotechnology trends that are occurring throughout the world today. Despite the fact that many analysts have labeled the 21st Century the "biological century," the broader implications stemming from the spread of recently developed biological and chemical processes and procedures have yet to receive much attention in the literature on international relations and strategic security.

This is an unfortunate situation because the development of civilian biotechnology in developing countries, much like other patterns of development in an era of globalization, mirrors the evolution of the biotechnology revolution in the United States. Many biotechnology companies in the United States today grew out of a partnership between the federal government, who provided funds for much of the early basic research in several fields, universities, and private companies. Federal research funds and contracts also played a key role in developing new private biotechnology applications. This loose partnership among government, universities, and corporations, especially in the fields of genetics, chemistry and other sciences, produced a wealth of insights and products in the United States that we now lump under the rubric of "biotechnology."

A great deal of current effort in the developing world is currently focused on biotechnology applications in agricultural and industrial goods because these fields are already highly lucrative and rapidly growing sectors. A recent estimate by the consulting firm McKinsey and Co. estimated that by 2010 chemical sales from biotechnology will top $US 140 billion. This figure is a substantial increase from the $50 billion spent today.[61] The magnitude of the current emphasis on developing consumer products is such that several industry analysts now characterize industrial biotechnology activities as the "third wave," following a first and second wave in medicine and bioagriculture respectively.

As the "third wave" of the biotechnology revolution gears up, extensive efforts are already underway throughout the world to develop biotech applications across several fields using "fourth wave" techniques that combine recent innovations in bioinformatics and proteomics. The new methodologies are speeding up the development time needed to produce new products and are permitting researchers to produce products for highly specific applications very rapidly. Much of the decrease in product development time is related to the fact that new types of computer modeling and testing can often eliminate the need for laboratory or animal studies. In medicine, the new technologies have already quickly produced new vaccines designed to block particular biological and viral agent in humans. After the anthrax attack in the United States in 2001, researchers sponsored by the Office of Naval Operations were able to develop a new target-specific vaccine in less than eighteen months. Today the development time would be much shorter. The rapid development of new smallpox vaccines, and ongoing efforts to produce a vaccine for the SARS virus, illustrate one important thrust of "fourth wave" biotech methodology.

Most of the developing countries who are currently participating in the civilian biotechnology revolution have adopted a national biotechnology strategy that provides government research and development support to aid civilian biotechnology research and development activities. Most of these governments view the development of a civilian biotechnology sector a high priority ranking along side information technology as valuable sectors to promote. Many of these countries are replicating the United States experience by supporting the development of civilian applications of biotechnology through a number of different public-private partnerships. Today, research and development is occurring worldwide in an effort to produce new process, procedures, or products that can be scaled up and sold to companies in the developed countries, or in a few cases manufactured in the home country. New product lines are being developed in several different fields including medicine, industrial production, environmental cleanup, animal and plant husbandry, cosmetics, and commercial agriculture.[62]

While the biotechnology sectors in most of these countries are small, each country is seeking to attract foreign and national biotechnology companies who will support one or more biotechnology R&D divisions, to promote the development of new biotechnology startup companies, and to expand the pool of well-trained and creative scientists who are interested in helping their country develop niche markets in areas that are widely accepted to be ones that will experience rapid growth in demands in future years.

One factor fueling the interest of many government officials and scientists in the developing world is future projections that genes may replace petroleum as the basic unit of commerce as the world economy shifts "from the hydrocarbon molecule to bio-based fuels."[63] Whether this shift will occur as completely and as quickly as predicted, the thesis is an important one to consider as it suggests the possibility of major and possibly even revolutionary impacts flowing from biotechnological advances in economics, military, and political relations in future decades. According to Robert Armstrong, one of the more important security implications of a shift to a bio-based economy would be to make relations with oil-rich countries less important, and relations with gene-rich states—mostly the biodiverse regions along the equator—all assume greater significance. Conflicts may arise between gene-rich, technology-poor countries that control the basic raw materials of a bio-based economy and gene-poor, technology-rich nations that control the production methods."[64]

Armstrong goes on to predict that America's instruments of power will increasingly be challenged by a shift to a biobased economy. He asserts that a large agricultural sector will become as important as today's oil fields because the agricultural industry will provide the most cost-effective way to manufacture large volumes of biological materials for food and fuel in the future.[65] Although Armstrong's assumption that technological innovations can solve the world-wide water shortage is highly questionable, his focus on the growing importance of the developing world's rich plant and animal gene pool as a source of new products in the midst of a biotechnology revolution serves as a source of inspiration to many government officials and biotechnology researchers in developing countries who are seeking ways to break through a world trade system dominated by companies housed in the developed world.

Another widespread assumption still held by many analysts in the west, who are interested in possible proliferation threats that may be hidden behind civilian biotechnology research, pertains to access to sophisticated bioinformatics computing facilities and gene, tissue, and protein libraries. There is a widespread belief that access to powerful computers and relevant libraries will be limited and serve as a constraint on the number of users who have access to state-of-the-art genetic modifications techniques in the future. Despite the flurry of recent research activity focused on the dual-use potential of civilian biotechnology, there have been remarkably few empirical studies of recent trends in biotechnology in developing countries. This is especially true for countries in Africa that is widely assumed away as a marginal area with few interesting research or development trends. The lack of interest in what is actually going on in developing countries is surprising since nearly every state in the developing world, including several African countries, is seeking to develop the scientific-industrial capacity needed to compete in the biotech revolution.

A recent survey of civilian biotechnology trends in South Africa documented a similar pattern of government-public-and private partnership in several different industrial sectors. Not too surprisingly given the HIV/AIDS pandemic and the rising incidence of other infectious diseases, the most sophisticated biotechnology techniques currently underway in South Africa are found in the area of vaccine and drug development.[66] Many of the most sophisticated biotechnology research programs in medical research in South Africa today are collaborative research involving colleagues at South African and

United States or European institutions funded by private international foundations, foreign governments, or private investment.

To compensate for the limited resource and talent base, the South African government, much like government planners in other development countries worldwide, is supporting a number of biotechnology initiatives designed to promote the growth of a biotechnology private sector. One of the most ambitious initiatives in South Africa today is designed to promote more collaboration in sophisticated bioinformatics research in South Africa and the broader African contexts. The initiative, called the South African National Bioinformatics Initiative (SANBI), is in the process of connecting researchers at research universities, government research shops, and startup private biotech firms together in a national computer network whose central node will be at the University of Western Cape (UWC). UWC houses the country's only Cray super computer that is available for use for biological research. When the SANBI consortium of researchers at universities and public-private institutes is completed within the next couple of years, researchers at major universities and in several other research institutes will be able to conduct fourth-generation proteomics and genomics research using the UWC computer and state-of-the-art bioinformatics software. Perhaps even more significantly, researchers at historically disadvantaged laboratory facilities will have access to gene, tissue, and protein libraries and data bases.

SANBI was started by Dr. Winston Hide, an internationally known bioinformaticist, who established an international reputation for his work isolating the gene for hereditary blindness. Dr. Hide returned to South Africa after working in commercial pharmaceutical research and research sponsored by the US Department of Energy in the mid-1990s and started SANBI with one post-doctorate. The bioinformatics program at UWC now has five doctoral students training in bioinformatics. He is the principle architect for the national bioinformatics research center and a magnet who attracts world-class researchers to UWC.[67] In April 1996, researchers who supported the master plan concept behind SANBI at several universities (i.e., Pretoria and Rhodes in South Africa, University of Pisa in Italy) came together to develop a SANBI plan built around the Cray computer at UWC with key local node resources in structural bioinformatics at the University of Rhodes, Pretoria, and several other universities and the Council for Science and Industrial Relations (CSIR). A new Africa Center for Gene Therapy (ACGT) was established at the Council for Scientific and Industrial Relations in Pretoria to ensure that industrial researchers affiliated with CSIR also have ready access to the national network.

SANBI's mission has three components: 1) research, 2) training, and 3) to serve as the national server (NCBI) for universities and other research entities that will be connected to the SANBI computer network. A national computer network is nearing completion in South Africa. Once public and private research and industrial laboratories are connected to the SANBI computer network, the next task will be to implement the longer-term goal of providing access to researchers throughout the African continent. Thus, within a decade the SANBI network hopes to link researchers in South Africa and Egypt, the two countries who are conducted the most sophisticated biotechnology research, with researchers with similar interests at research centers of excellence throughout Africa. This new network will allow researchers in even very poor African countries, such as Sudan, to have access to high-speed computer capabilities and several different gene, tissue, and protein libraries.

The current South African “SANBI vision” for a continental-wide bioinformatics network envisions every African country having one or more centers of excellence where sequencing research can occur. Each of the centers will require seed money and computer infrastructure, including dedicated computer lines. Most South African researchers and government officials involved in biotechnology research and development believe that other African countries should develop a coordinated national program similar to one initiated by Brazil to promote domestic biotechnology research and development. [68] Thus, many South Africans are working to establish regional hubs throughout Africa that are similar to the biological research and innovation centers being set up in South Africa today.

While the SANBI network is still in the process of being set up, the ambitious goals of this government-university-private sector initiative illustrates how irrelevant past notions of limiting access to the expertise and databases necessary are for future potential dual-use applications of civilian biotechnology research. If sophisticated bioinformatics research is conducted in the near-term future in such poor African countries as Tanzania, one would be prudent to assume that similar collaborative efforts are being taken in economically more affluent regions of the world as well.

Moreover, recent United Nations activities complement or mirror many of the goals found in South Africa’s development plans. Several units of the UN have recently called for an increase in the biotechnology and computer capacities of African countries. The establishment of regional bioinformatics centers of excellence was identified as an important goal of the UN Environmental Program at the Cartegena Conference. A Forum on Biosafety, established at the Cartegena Conference, is also supporting the establishment of regional centers that are capable of conducting research on the safety of new GMOs in food products.

The city of Nairobi, Kenya has already been selected as the future regional center for Africa. The United Nations is also sponsoring a number of program and conference activities that collectively should increase the biotechnology capacity of African countries over time. For example, at a recent conference sponsored by the United Nations Industrial and Development Organization (UNIDO) in Nairobi, Kenya delegates came up with a shopping list of the types of biotechnology projects that 17 countries in the developing world should undertake.

The list of important projects for Africa focused on increased food security. Specific programs recommended for African nation-states included research on BtMaize, viruses specific to African crops (e.g., virus recsi), parasitic weeds, funal toxins (e.g., BT maize), and how to counter drought. To implement these programs, UNIDO and the UN leadership are encouraging African countries to adopt a cooperative regional approach whereby each country has a certain percentage of research funds and a different set of rules to guide research.[69]

Establishing national and regional research centers capable of doing sophisticated research is now a priority of several non-governmental organizations and governments who fund development projects in Africa. More recent funding initiatives designed to help African countries develop an indigenous capacity to produce generic drugs to combat HIV/AIDS and other infectious diseases and thus reduce their dependency on high-priced drugs from global pharmaceuticals are also calling for more medical research capacity. One Swedish non-government organization has supported the development of biotechnology capacity throughout East Africa as its primary mission. These efforts are succeeding in building new biotechnology capacity. For example, the East African Research Institute at Mekere University in Uganda currently has a modern laboratory capable of supporting research in the area of agriculture and environment. Laboratory research on the maize tree virus is already underway. Researchers working at the new institute also have access to modern computer facilities at the Hillary Clinton Bioinformatics Computer Laboratory.

The recent additions at Mekere University appear to be part of a wider trend of establishing and upgrading existing research facilities throughout Africa. Today, there are several research centers that have the laboratory facilities necessary to undertake second- or third-generation research. Many of these facilities are run by international organizations affiliated with the United Nations or are national efforts that have been able to improve their facilities with funds from outside donors. There are now Laser centers in seven countries. The World Health Organization runs a Tropical Disease Research Institute in Tunisia. In Algeria there are no national agricultural institutes doing GM work but there is at least one research project sponsored by CTIGR. Algeria also has a large scientific community that has the training to conduct biotechnology R&D research in the future.

Two other African countries already have developed national biotechnology strategies. Lesotho recently developed a strategy for dealing with genetically modified organisms. Nigeria has formulated a national biotechnology strategy. Although little progress has yet been made yet in implementing the policy goals articulated in the national plans, President Obasanjo of Nigeria recently insisted that biotechnology be listed as a priority in the most recent national agriculture budget. Nigeria also has several research institutes, such as

CEPEI, and many established universities that can serve as the basis for sophisticated biotechnology R&D in the future.[70]

Food insecurity, the global debate about whether GMO agricultural products can be exported to Europe and rising rates of certain infectious diseases such as HIV/AIDS, and the need for inexpensive generic drugs and vaccines, are the major factors driving new science R&D policy initiatives in several African countries.

A final initiative that should be noted is the African Genome Project. African scientists are quick to point out that no Africans worked on the Genome Project. To make up for this oversight and to promote increased coordination and cooperation among African scientists working on advanced biotechnology research, a group of researchers in South Africa initiated the series of annual conferences. The first African Genome Conference was held in South Africa in 2003. For the 2004 conference, the South African academics partnered with Egyptian researchers at the Ain Shams University in Cairo. The South African researchers stressed that they were impressed by the amount of biotechnology capacity and research currently being conducted in Egypt. Their vision is for these two states to play important anchor roles in helping to build capacity and coordination among research centers in other parts of Africa. The 2005 Conference is scheduled to take place in Kenya and will be held at either Kabete or Narobi University. The Kenyan International Livestock Research Centre is another host partner for this planned event.

This brief review of only a few of several initiatives being sponsored by the South African government and the United Nations to promote biotechnology research and development in Africa suggests that there already exists a great deal of human and physical capacity in several African countries to engage in sophisticated biotechnology research. An important constraint on fourth-generation bioinformatics research (i.e., advanced genomics and proteomics research) in South Africa, Africa, and throughout the developing world in the past was the limited access to wide enough band width, high-speed computers, and databases needed to do sophisticated informatics research. However, the SANBI consortium and other ongoing initiatives in Africa suggest that limited access to sophisticated bioinformatics computing facilities and gene, tissue, and protein libraries will not be a limiting factor on users who are able to gain access to state-of-the-art genetic modifications techniques in a number of developing countries, including some of the poorest ones in Africa,[71]

At one end of the spectrum is a widely held belief among experts in the developing world that indigenous naturally occurring pathogens are the most likely bioagents to be used as biological weapons. These views are remarkably similar to the early research activities of Iraqi biowarfare researchers. Many experts throughout the developing world believe that economic disruption or financial blackmail rather than mass destruction are more probable goals of nation-states or terrorist groups than mass destruction. A recent action by the Australia Group reflects concern about smaller and more mobile equipment that can be used in covert biowarfare. In 2002, the AG passed new export restrictions on small fomenters, and in 2004 it prohibited the export in five plant pathogens.[72] However, recent advances in developing highly mobile bio-science laboratories and other technological advances suggest that the strategy of attempting to control exports will increasingly become an ineffective strategy in the future.

The genome revolution and the spread of information networks allows users in remote locations to conduct sophisticated research is a new, extremely complicating factor for the biological nonproliferation regime. As access to sophisticated bioinformatics capabilities and gene and protein libraries spreads throughout the world, there is an increased danger that future biowarfare scientists or terrorists will start experimenting with state-of-the-art techniques to produce novel weapons. Ironically, SIPRI, cited by one Iraqi scientist above as the initial source for literature searches when Iraq attempted to restart their secret biological weapons research program, is now one of the few organizations that is warning about the new opportunities for novel biowarfare weapons present in bioinformatics capabilities and state-of-the-art proteomics and genomics methods that are now spreading around the world.

WAYS TO MONITOR EMERGING DUAL-USE BIOLOGICAL PROLIFERATION THREATS

Civilian biotechnology and the information revolution are two sectors that virtually every country with any science and technology capacity wants promoted. Most countries around the world are copying the United States model of encouraging a partnership among key players in government, the private sector, and universities. This trend means that it is increasingly important to understand trends in the political economy of civilian biotechnology in order to understand future biowarfare trends.

One of the most important trends in civilian biotechnology in the developing world today is the fact that most countries are trying to find a “niche” market in a world political economic system dominated by multinational corporations and biotechnology startup countries located in the economically advanced countries in North America, Europe, and Asia. Competition for market shares in biotechnology global markets is already fierce. Thus, many groups of biotechnology entrepreneurs in developing countries are attempting to demonstrate “proof of concept” in order to sell a patented process or product to a multinational corporation. The result is that many more actors—nation-states, multi-national corporations, and government owned parastatals, nongovernmental organizations, private biotech startup companies, and even individuals—are increasingly seeking unique partnerships or "networks" in order to market their products around the world. While most of the attention in bioterrorism research has focused on such well-known networks as al Qaeda and its offshoots, there are also several other types of networks that are engaging in collaborations using civilian biotechnology to achieve a shared economic rather than political objective. Figure 1 illustrates one such economic network

Figure 1: Vaccine Manufacturers Network (DCVMN)

Full Members Serum Institute of India Fiocruz/Biomarguinhos Brazil Shantha Biotechnics, Pvt. Ltd. India P.T. Biofarma, Indonesia CIGB, Cuba Institut Pasteu, Dakar Sengal	**Prospective Members** Instituto Butanto, Brazil Panacea Biotech, India Instituo Finlay, Cuba Biological E. India
Observers Thai Red Cross Thailand Institut Pasteur de Tunis , Tunisia Thai GPO Thailand (generic anti-viral pill) IVAC, Vietnam	**Associate Members** Birmex, Mexico Lanzhou Institute, China Vacsera, Egypt Chengdu Institute, China Shenzen Kangtai, China Pasteur Institute, Iran

Source: FBIS, 2001

that was formed among a host of different types of actors in 2001 with the goal of developing genetic vaccines. The network is working to produce both products that can compete with more established vaccine suppliers at lower prices and generic vaccines that large pharmaceutical multinationals no longer produce. Several aspects of this network are notable. First, it is composed of different types of entities, including state-run, parastatal, and private research institutes, along with non-governmental organizations. Thus, the funding is coming from both private and public sources. Second, several of the research institutes included in the list were at some point in the past suspected in being possible dual-use research and development sites.[73] Third, since 2001 several of these research sites have sought to expand their network further to find other state or multinational partnerships. Thus, for example, Haber Corporations, the biotechnology startup company of the CIGB Research Institute of Cuba, recently entered an agreement with a European multinational drug company to engage in further vaccine research and development. Haber also signed an agreement in 2003 with a newly privatized vaccine company in South Africa, BioVac, in order to produce six or seven vaccines that are not being produced by major pharmaceutical companies.[74] These recent international collaborations illustrate the fact that more and more research labs and biotech startup firms in the developing world in the future are likely to forge international links. In such an environment, the public or private laboratory that avoids international partners or is not following "good laboratory standards and practices" established by national governments and international bodies is likely to increasingly stand out as an "outlier" in an increasingly internationalized biotechnology economy.[75]

The fact that the world political economy for biotechnology is already so highly globalized can be used to develop a preliminary classification scheme to track potential dual-use civilian biotechnology activities within different types of nation-states in the future (see Table 1). One parameter used to construct the table relates to a country's

Table 1: Four Tiers of Countries Engaged in Civilian Biotech*

TIER 1: Dominant biotechnology countries—"The West": US, Europe (Russia), and offshoots (Japan, Australia) **TIER 1A:** Nations in developing world with significance biotech growth potential—India and China
TIER 2: Countries with some biotechnology human and physical capabilities—Israel, South Korea, Brazil,South Africa, Nigieria, Kenya, Singapore, Thailand, UAE, Dubai, Algeria, Egypt, Malaysia, Cuba, Sudan, Pakistan, Iran, North Korea
TIER 3: Countries with an interest but with little chance of developing civilian biotechnology commercial activities—The rest of Latin America, Asian-Pacific, Africa (island states, Mauritania, Caribbean states, Tanzania, Eritrea)
TIER 4: Collapsed States—Democratic Rep Congo; Somalia

*Note: The listed countries are designated to illustrate the type of countries in each category. This is not an exhaustive list of all countries with some biotechnology potential.

economic position, including the government's interest in developing biotechnology, and the human and physical capabilities available to produce civilian biotechnology. These types of indicators combined with more aggregate economic statistics could be used to develop a score of a country's degree of engagement in the world biotechnology economy. The second parameter used to construct the table arrays countries along a continuum based on the government's commitment to biological nonproliferation norms, treaties, and laws. Thus, a country with a high commitment to biological nonproliferation would be one that has signed the 1972 Biological and Toxin Weapons Convention (BWC), routinely attends BWC meetings, is a member of the Australia Group, and actively works to enforce export controls on proscribed biological (and chemical and nuclear) materials.[76]

A country's overall level of economic development and the human and physical capital needed to engage in civilian biotechnology helps locate specific countries in one of four levels or tiers of nation-states who are engaged in civilian biotechnology activity. The countries listed in Tier 1 of Table 1 are those located in the western world and their geographical or historical offshoots. While this is hardly surprising, what is notable is the fact that this classification system suggests that standard criteria that lump "Western" or economically advanced states together may be changing when one focuses only on one or a few high tech economic activities, such as biotechnology or information technology. When one narrows one's focus, it is clear that there is an important subset of countries that are already at or near the same level of research and development in biotechnology across several different sectors when compared to economically developed western countries. This set (Tier 1A) currently includes only two nation-states: China and India. Both countries have committed substantial resources to building biotechnology industrial parks, research facilities, and university programs that already rival or excel what's available in western countries. If both countries continue their current high rates of macroeconomic growth, and manage to avoid political conflicts or widespread instability at home, they both will soon close the gap in terms of facilities, human capital, and physical infrastructure with the US and Europe.

The main reasons why these two countries are not already grouped with other developed nation-states is because there is some doubts about whether and the extent to which India's and China's support the biological nonproliferation norms embodied in such principles as the BWC, the Australia Group, and economic norm-setting bodies such as the World Trade Organization. Long a flagrant violator of international copyright law, most support for China's recent admission into the World Trade Organization was based in part on the idea that China would be more likely to become a "normal state" as she grows economically if the government was a member and had a voice in the WTO.

Future analyses should pay close attention to China's commitment to biological nonproliferation norms at the same time that trends in civilian biotechnology within the country are monitored. Similarly, as the possibility of a nuclear, chemical, or biological exchange between India and Pakistan grows more remote, the hope is that the goal of increased participation in the international economic system will overtake any existing commitment to developing covert biological weapons. The very real possibility of some political unrest in China in future years or a regime change in Pakistan and thus a radical change in the threat perceptions of India's leaders might change the current assessments. Moreover, commitment to developing civilian biotechnology sectors does not preclude the existence of a secret weapons program. However, as a country becomes more affluent and more integrated into the world economic capitalist system, the political costs of maintaining covert weapons program also increase. Thus, the possibility exists that world economic integration may help to reduce support for secret weapons research within rising economic states.

The countries included in Tier 2 illustrate even better the harsh reality that the development of civilian biotechnology capabilities does not preclude covert research or development of covert weapons of mass destruction. However, this group of nation-states shares several important characteristics in terms of their commitment to develop civilian biotechnology applications and the willingness of the government to support such activities through national biotech plans, policies, and business-friendly tax laws. At the same time, these countries vary on a number of important economic criteria related to developing advanced biotechnology applications including:

-the size of their biotechnology human or physical capacity

-the size of public and private involvement in biotechnology R&D

-the amount and source (pubic or private) of investment capital for biotech R&D

-the size of the state sector, and role played by parastatal and private biotech companies

-the role of the government in regulating biotechnology research

-the size and quality of education programs designed to train future scientists and engineers, and technicians

-the extent of foreign collaborations and efforts to engage in world capitalism.

These nation-states also vary in terms of their commitment to the chem-bio non-proliferation regime and adherence to existing treaties, laws, and norms. When the nation-states in this tier are arrayed from left to right on the basis of the strength of their commitment to biological nonproliferation norms, one begins to see how intertwined a country's integration into the world political economy is with their commitment to WMD norms. Given the defining role of the two parameters it is hardly surprising that North Korea is at the far right end of the commitment to nonproliferation norms dimension. This continuum of the classification system further illustrates the importance of a country's involvement in the international economic system, in addition to the political orientation of the government, in terms of whether or not a particular government is likely to be supporting secret covert biological weapons research at any given point in time.

Tier 3 countries are grouped together because they largely function as labor reserves and off-shore tax shelters for multinationals, or as junior partners in western collaborations. While several of the countries in this group have expressed an interest in developing biotechnology sectors as a way to generate much more foreign capital and jobs, none of these countries at this time have the minimal amount of human and financial capital, or the physical infrastructure, needed to generate indigenous biotechnology research and development. While some of these countries have succeeded in attracting foreign investors, most of these investments are not value-added collaborations that will increase the wealth or knowledge of citizens or the government of the country.

Tier 4 is the set of countries where governance has collapsed and there are large portions of the country where terrorists, drug lords, or other types of network can easily set up shop and perhaps also a "bush chem-bio research and production" facility. While this type of scenario is widely discussed, remarkably little unclassified research has been directed at identifying the ungovernable areas of the developing world where terrorists and other groups can operate free from outside observers or intrusions.[77]

CONCLUSION

Future efforts to monitor civilian biotechnology activities in conjunction with possible dual-use activities for all countries in the world constitute a huge task that requires more structure to be a manageable monitoring task. The framework used in Table 1 suggests that the number of countries who have the physical and human capabilities needed to engage in civilian biotechnology is still relative small. Institutional constraints are another problem to future monitoring efforts since the analysts who are paid to monitor biological, or chemical, or nuclear threats are not the same individuals as those whose portfolio it is to monitor scientific and industrial developments in particular countries or regions. It may be necessary to impose additional institutional requirements, such as the development of integrated databases and annual or biannual reports, in order to get analysts in different missions around the world or those working in different departments of government agencies to collaborate in analyzing the proliferation implications at the nexus between civilian biotechnology and biological proliferation. The spread of biotechnology expertise and capabilities around the world suggests that such data gathering and analysis efforts are important activities that should be undertaken.

The research reported in this paper is based on the assumption that current control strategies designed to limit access to biological research and development (R&D) knowledge, or specific pieces of equipment, supplies, bioinformatics programs, gene and protein libraries that can have dual uses are inadequate for dealing with the proliferation of biotechnology in the world today. Control strategies such as import controls, sanctions, and arms control agreements, combined with efforts to enforce arms control agreements or by resorting to military counter-proliferation measures, may slow down the acquisition of certain dual-use biotechnology knowledge or equipment. However such strategies will be unable to stem the tide of spreading biological knowledge and capabilities throughout the world because of the growing demands for high tech jobs and economic activities in most countries of the world. There is a scientific and economic imperative fueling the spread of biotechnology that is resulting in a myriad of new commercial applications. Basic research is being translated into new processes and procedures in a variety of fields ranging from agriculture, drugs, vaccines, new industrial processes and products, to environmental waste clean-up and disposal.[78] New knowledge is being generated on a regular basis as new automatic techniques now make it possible to sequence the genome for other animals and plants in a matter of weeks or months rather than years.[79]

The explosion in new knowledge is why more and more analysts are now speculating that historians will characterize the 21st Century as the "biological age." Recent trends in the globalization of trade and communications reinforce further the sense that it is already impossible to stem the flow of biological knowledge and nearly impossible to stop the flow of dual-use equipment throughout the world. Most of the attention to date has focused on the wealth of new insights and products that have been produced in the developed world.

Nearly every nation-state in the developing world with some minimal scientific and industrial capacity has identified biotechnology, along with information technology, as desirable economic sectors to promote in order to generate high tech, and thus high value, products that can be exported and in order to create new, high paying jobs. The promise of future economic gains associated with high tech biotechnology, has led nearly every country in the developing world with any scientific capacity to develop national biotechnology strategies and incentive programs to promote the development of biotechnology across a number of different sectors. The widespread belief that biotechnology may offer a promising new road to future economic gains probably more than any other factor is currently fueling interest in developing biotechnology capacity and new biostartup companies in many countries in the developing world.

While the economic incentives associated with biotechnology are desirable from an economic development perspective, the trend ensures that dual-use knowledge and facilities will continue to spread at an unprecedented rate when compared to the length of time that it took for the proliferation of expertise, critical materials, and equipment needed to produce nuclear weapons. The anthrax attacks underscored the extensive disruption that can be caused by releasing a small amount of a biological pathogen through the mail. Several analysts have now noted in public how many pathogens, such as anthrax and hoof-and-mouth that is indigenous in many countries of the world, can be used as biowarfare weapons. While many strategic analysts are still using analogies from past experiences with covert nuclear or chem-bio national programs, there is a growing realization that future uses of biological pathogens may involve naturally occurring pathogens and novel delivery devices rather than large quantities of weaponized BW agents and sophisticated, high tech delivery devices such as missiles.[80]

There is also a growing recognition that in the future the world may simultaneously face biological weapons threats from naturally occurring biological pathogens and genetically modified organisms. The skill set needed to produce such organisms is now routinely taught in graduate school.[81] Increasingly, computer distributed networks are making it possible for personnel working in geographically remote sites to have access to sophisticated bioinformatics computer programs, and gene and protein libraries. These resources can be used to develop novel new products or new types of biological weapons. These scientific and economic trends, combined with evidence that several nation-states and terrorist groups continue to be interested in acquiring biological weapons, suggest that it will be increasingly important in the future to develop additional approaches for monitoring suspected dual-use activities throughout the world and to find new ways to manage this still poorly understood class of threats.[82]

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NOTES

[1] The specific policy recommendations for the USG are discussed in more detail in a report designed to examine future trends in biotechnology research in the developing world. The report is Helen Purkitt, with scientific support by Dr. V.G. Wells, *What's over the biotechnology horizon: Biotechnology research and development trends in South Africa.* Final Research Report to the Advanced Systems and Concept Organization of the Defense Threat Reduction Agency, February, 2004.

[2] Most covert programs in the developing world offered foreign study or training as an incentive while recruiting scientist. See Helen Purkitt and Steve Burgess, *South Africa's Secret Weapons of Mass Destruction*, Bloomington, IN: Indiana University Press, 2005 and Steve Burgess and Helen Purkitt, the *Rollback of South Africa's Biological Warfare Program*, INSS Occasional Paper 37, US Air Force Academy, February, 2001, for details about the importance of foreign study and training for the first generation of South African scientists who worked on the secret weapons program called Project Coast.

[3] For example by the mid-1990s, a chemist named Dr Muhammad 'Abd Al-Mun'im Al Azmirli, an Egyptian, was playing a lead role in conducted experiments on prisoners with ricin to determine its effectiveness as a biological weapons. Many colleagues blamed Dr. Muhammad' Abd Al-Mun'im Al Azmirli, who is now deceased, for the more odious acts undertaken by members of the Iraqi bw program in debriefings with American investigators in 2004. See Duelfer, Volume 3, 1-10 for more details.

[4] Duelfer Vol. 3: 1 and 6.

[5] Ibid.

[6] Purkitt and Burgess, Chapters 5 and 7, 2005; Burgess and Purkitt, 2001.

[7] Interview with Dr. Hans. G. Jager, Avimune (PTY) Ltd., the largest private poultry pathology lab in Africa, and former Director of Research and Development, Onderstepoort, Durban, South Africa, 1 July 2003.

[8] Interview with Dr. Hans G. Jager; see also Purkitt with Wells, 2004.

[9] Purkitt and Burgess, op. cit.

[10] In the case of South Africa, Project Coast turned to a US microbiologist with ties to the earlier biological warfare program in the US named Dr. Larry Creed Ford. For more details see Victor Ray and Helen Purkitt, *Emerging threats to US homeland security: A case study of the use of biological weapons for personal & political motives in California and South Africa*, (forthcoming).

[11] Duelfer report, Vol. 3: 10.

[12] Research on Brucella was also conducted at Abu Ghurayb Veterinary College but no information on the extent of this work was available to American investigators. Duelfer, Vol. 3: 23.

[13] Mark Wheelis, *Agricultural Biowarfare and Bioterrorism,* Edmonds Institute Occasional Paper, 2000 (http://www.edmonds-institute.org/wheelis.html).

[14] See Purkitt with Wells, 2004.

[15] This or a similar observation is found in nearly every published article in scientific magazines and journals, i.e., *Nature* or *Science*, that discusses future bioterrorist attacks.

[16] See the Australia Group web site at: http://www.cbwinfo.com/General/Australia.html.

[17] For a description of the Russian program, see Ken Alibek, *Biohazard*, Random House., 1999.

[18] See for example, Wheelis, op cit.

[19] Rolk Ekeus, "Reassessment: The IISS Strategic Dossier on Iraq's Weapons of Mass Destruction, *Survival*, Vol. 46, 2 (Summer 2004): 78-9.

[20] Duelfer, Vol. 3: 8.

[21] Duelfer, Vol. 3: 1.

[22] Duelfer, Vol. 3: 11.

[23] Wheelis, op cit.

[24] Duelfer, Vol. 3: 9.

[25] Matt Moore, "Global military spending soars during 2003; nearly half by US," Associated Press, 9 June (BC Cycle) 2004.

[26] Duelfer, op cit.

[27] Ibid, see William Rivers Pitt, with Scott Ritter, *War on Iraq*, New York: Context Books, 2002, 237.

[28] Accounts of the quick diagnosis of the two mobile labs as weather stations is based on interviews with several experts who were either members of the team or involved in the effort to identify the purpose of these vehicles: Interviews conducted during 2004 with former weapon inspectors and analysts who did not wish to be identified.

[29] Scott Ritter, *Endgame: Solving the Iraq Crisis*, New York: Simon and Schuster, 1999/2002, 237.

[30] For more details, see Helen Purkitt, "International Political Economy and National Security Implications of the Biotech Revolution," Paper presented at the ISS Section panel, "Thinking Strategically about Biological and Chemical Weapons," at the International Studies Association Annual Conference, Montreal, Canada, March 19, 2004.

[31] Jackson, Payne, and Odelson "Liquid-culture production of blastospores of the bioinsecticidal fungus Paecilomyces fumosoroseus using portable fermentation equipment," *J. Ind Microbiol Biotechnology* 31 (2004): 149-154.

[32] Sylvia Pagan Westphal, "Handmade cloning cheap and easy," *New Scientist*, 14 August 2002, NewScientist.com (accessed October 24, 2002).

[33] Phone interview with Dr. Mark Winfield, University of Pretoria, Plant Biotechnology, Agriculture, Crops, and Forests, 13 June 2003.

[34] Westphal, op cit.

[35] There are three companies manufacturing and selling mobile, modular bio-science level 2 and 3 labs in the United States. Two of these companies sell via the internet.

[36] For more details contact the Australia Group web site at http://www.cbwinfor.com/General/Australia.html

[37] Duelfer, Vol. 3: 10.

[38] Duelfer, Vol. 3: 10-14.

[39] Ibid.

[40] Ibid.

[41] Ibid. 14.

[42] For a recent review of this historical period, see Rolk Ekeus, op cit.

[43] Duelfer, Vol. 3: 14.

[44] Duelfer, Vol. 3: 24.

[45] Ritter, 1999/2002, 235.

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[46] Ekeus, op cit.

[47] Duelfer, op cit.

[48] Duelfer, op cit.: 16.

[49] This account is taken from Gerald Fink, Ronald Atlas, W. Emmett Barkley, et al, *Biotechnology Research in an age of Terrorism: Confronting the Dual Use Dilemma*, Washington DC: National Academy of Science Press, (pre-publication copy) 2003.

[50] Although the Fink report has received extensive press coverage, there were several earlier studies commissioned by the National Academy of Science and other public bodies since the early 1990s that have warned of the potential for biowarfare misuse in emerging biotechnology and chemical research. See Mark Wheelis, Malcolm Dando, and Catherine Auer, "Back to bioweapons," *Bulletin of the Atomic Scientists*, Jan/Feb, 2003: 40-46 for a summary of some of the new techniques that are of concern.

[51] See for example Elise Harris's unpublished report on industry and government responses, University of Maryland, 20 February 2004; a forthcoming report by the Center for Biosecurity at the University of Pittsburgh, and another forthcoming report by the Chemical and Biological Arms Control Institute of Washington DC. Announcement of later two reports made at the "Pandemics & Bioterrrorism: Industry & Government Responses," WIIS Science, Technology & Security Policy Forum, 20 February 2004.

[52] "Board Set up to Keep Research out ob Bioterrorists' hands," *Washington Post*, 5 March 2004, A6.

[53] While this point was made by several of the life scientists interviewed for this study, none of these scientists wanted to go on the record with such a dire prediction.

[54] Special pathogens are a designated group of viruses, bacteria, and toxins that are highly contagious, or for which there is no known cure, and that therefore require special handling and equipment in Bio-Science Labs at the highest levels, i.e. BSL-3 or BSL-4. While the terms biological pathogens and agents are used interchangeably in this paper to designate many different types of organism there are important distinctions among different types of viruses, bacteria, and toxins. Biological agents are found in nature; are usually capable of self-replication, and have the capacity to produce deleterious effects on other organism, particular humans. In contrast, biological materials are not capable of self-replication and are the components of biological agents that present a real or potential risk of causing illness or injury to humans, plants, and animals. Examples of

bioharardous material are ethiologic agents and toxins. Biological Toxins (Biotoxins) are non-living biohazardous proteins that are naturally produced in many different types of living organisms and are thousands of times more toxic per weight than chemical agents. Toxins that produce natural microorganism are considered to be in the same risk category as those organisms by themselves. These definitions were provided by Alfred Jin in a presentation entitled "Comprehensive IH Review: Fundamentals of Biohazard Control," presentation prepared for the Hazards Control Department, Lawrence Livermore National Laboratories, July 2004.

[55] In 1989, Dr. Muzhir (Mudher Moder) Al Falluji, one of the leading biologists working on the Iraqi secret biowarfare program, tried to get the Ames strain of B. Anthracis which he considered "very virulent" while attending a scientific workshop abroad. He was unsuccessful in that endeavor. According to Thamir'Abd-al-Rahgman, a key figure in Iraq's anthrax program, the Iraqis had to settle for the American Type Culture Collection (ATCC) strain 14578 as the sole strain of anthrax that was developed by the Iraqis as a BW weapons. Duelfer, Vol. 3.

[56] "Foreign students raking it in for the US," *Times News Network*, 19 November 2004. It should be noted that it is also too soon to determine the exact nature of what appears to be a complex trend in terms of the numbers of types of foreign students coming to the United States. US public funding for international students has increased dramatically in recent years. The US government funded 10,111 international students in 2003-04 as opposed to just 3,085 in 2002-03. This was a 228% increase. At the same time, students funded by private US sponsorships fell from 14,366 to a modest 2,921 in 2003-04, a decline of close to 80%. According to statistics supplied by the Dept of Commerce, 81.8% of international students at the undergraduate level rely on personal funds; only 10.8% are funded by their university. The figures are from the Open Doors survey for 2003-04 conducted by the US Institute of International Education.

[57] Associated Press, "Drop in foreign grad students raises alarm," 5 November 2004. See also Julie Sneider, "International brain drain: Post-9/11 restrictions discourage foreign students in tech, science fields," *The Business Journal of Milwaukee Online*, http://milwaukee.bizjournals.com/milwaukee/stories/2004/05/24/story2.html (Accessed October 2, 2005).

[58] Sneider, op cit.

[59] Ibid.

[60] Purkitt with Wells, op cit.

[61] Michael Babbaro, "Wake up and smell the science," *Washington Post*, 15 June 2003, F1, F6. This estimate includes projected earnings from the

large biotech busses such as DuPont, Archer, Daniels Midland Co., and Dow Chemical Co.

[62] For a more in depth overview of trends in the developing world that is still relevant, see G.T. Tzotzos and K.G. Skryabin, *Biotechnology in the developing world and countries in economic transition*. New York: CABI Publishing, 2000.

[63] Robert E. Armstrong, "From Petro to Agro: Seed of a New Economy," *Defense Horizons*. No. 20 (October 2002): 1.

[64] Ibid.

[65] Ibid. 2.

[66] Purkitt with Wells, 3.

[67] Interview by Helen Purkitt with Renfree Christie, Director of Research, UWC, Cape Town, 8 July 2003.

[68] See Purkitt and Wells, 2004 for more details.

[69] Interview by Helen Purkitt with Professor Thomson, University of Cape Town, 10 July 2003.

[70] Interview with Professor Thomson, 10 July 2003.

[71] The POC for more details about the computer capabilities of SANBI and details about how band width serves as a major constraint for bioinformatics research in South Africa and throughout the developing world is Caspir Schullter, SANBI, University of Western Cape, Bellville, South Africa, cschutte@icon.co.za.

[72] See the Australia Group web site at: http://www.cbwinfo.com/General/Australia.html.

[73] For more details about individual countries and sites see Monterey Institute of International Studies, Center for Nonproliferation Studies, *Chemical & Biological Weapons Research Page: Possession and Programs Past and Present* at http://cns.miis.edu/research/cbw/possess.htm.

[74] Purkitt with Wells, op cit.

[75] I am indebted to Dr. Daan Goosen, a former South African Project Coast scientist, who proposed during an interview with the author in June 2003 that "open transparency and freedom of information are the key way to control biowarfare threats" at the scientific level. His recommendation for monitoring the civilian biotechnology sector is to "get more countries in the developing world on international laboratory standards" used by the United States, the EU, and the OECD. South Africa has a similar body

that regulates Good Laboratory Practices (GLP) called the South African National Accreditation Service. This accreditation body certifies GLP based on an internationally recognized standard. The GLP systems of accreditation and regulation are based on "good faith" voluntary compliance so any lab that is not in compliance would be easier to spot once more countries adopted existing standards of accreditation and certification. While the approach does not address the problem of the "lab in the suburbs" or the bush, a focus on accrediting laboratories may be particularly well suited for developing countries where the number of public projects and private start-up biotechnology companies are still relatively small and where everyone seems to know what other biotechnology researchers are doing. Interview with Dr. Daan Goosen, Pretoria, South Africa, 26 June 2003.

[76] It is interesting to note that many governments chose not to attend routine meetings of signatories of the Biological Treaty during key periods when covert biological weapons research is occurring. While this is not a reliable indicator in and of itself, when combined with other indicators it may serve as a useful "red flag." I am indebted to Midn. James Saul's paper, USNA 2004, for a further discussion of useful indicators and signatures of possible covert biological research and development.

[77] For example, there have been reports that a Columbian drug lord set up shop in the south-east region of the Democratic Republic of Congo in the late 1990s. Similar rumors have been circulating around Africa for several years that there are al Qaeda camps in the Democratic Republic of the Congo and in other collapsed African states. However, there was little interest within the US and other western governments in investigating these types of reports until after 2001.

[78] The growth of new applications tied to the genome project is truly mind-boggling. For some sense of how widespread the development of new commercial applications of genomic basic research and techniques is, the reader is encouraged to peruse the table of contents or weekly announcements of such publications as *NatureBiotechnology*.

[79] Estimate provided by a tour guide at the Genome Sequencing Company, Walnut Creek, California, 4 August 2004.

[80] Recent government-sponsored exercises have documented how alternative delivery devices, including infecting one or a very few individuals in a crowded urban setting, could easily infect large numbers of individuals with a highly contagious virus such as smallpox.

[81] This point was stressed by Professor Judith Reppy, Science and Technology Studies, Cornell University in a phone interview during May, 2004. While this point is widely known to life scientists, the implication of

these new skills are only now becoming familiar to social scientists interested in national biosecurity issues.

[82] For another general overview of some of the emerging problems associated with the spread of biotechnology worldwide, see Christopher F. Chyba and Alex L. Greninger, "Biotechnology and Bioterrorism: An Unprecedented World, *Survival*, Vol. 46, 2 (Summer 2004): 143-162.