# Proliferation of Biological Weapons into Terrorist Hands

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Because of their relative ease of purchase and development, biological weapons have been called "the poor man's nuclear bomb." This paper examines the extent to which such weapons are likely to spread – in particular, to terrorist hands – and whether the United States and its allies effectively control their proliferation. It concludes that while we can and should take useful steps, biological weapons will proliferate and we will be unable to retard this proliferation as effectively as we retarded nuclear proliferation over the past 60 years.

## Biological Weapons: Why and How

Discussion of biological weapons is complicated by their diversity and their unfamiliarity. It helps, therefore, to focus on five "reference cases":[2]

(1) use of anthrax (a bacterium) in a major outdoor aerosol attack;

(2) use of smallpox (a virus) in an indoor aerosol attack (for example, through a building heating, ventilation, and air conditioning [HVAC] system);

(3) dissemination of a toxin,[3] such as botulinum, through the food supply, for example through cold drinks;

(4) spread of foot and mouth disease (a virus that does not affect humans) in cows, pigs, and sheep;

(5) the invention and dispersal of a pathogen that does not have the attributes of pathogens that exist in nature. All biological agents that appear on U.S. agency threat lists now exist (or in the case of smallpox, used to exist) in nature. This last case – sometimes now called "Case 5" or "Case X"[4]– is less pressing, but obviously more open-ended and therefore most complex.

Military thinking about biological weapons has long noted both their attractiveness and their limitations. Though it is sometimes said that there is no history of their use, examples are numerous, including the medieval practice of throwing cadavers into walled cities, British impregnation of blankets with smallpox, and Japanese infliction of plague on Chinese populations.[5] After World War II several nations invested in more sophisticated versions of these weapons. The United States ran an extensive program until 1969. Britain, which had planned an anthrax attack on Germany in 1943, extensively contaminated an island off Scotland through anthrax field trials. In submissions to United Nations inspectors, Iraq acknowledged a program into the early 1990s.[6] Long after forswearing biological weapons through the Biological Weapons Convention (BWC), Russia employed tens of thousands of people in an ongoing biological weapons program. Intelligence estimates reported in the press reference a number of other countries as having experimented with biological weapons – in particular, North Korea.[7]

There is no doubt that some biological agents can be weapons of mass destruction. Anthrax is prevalent in every program. *Bacillus anthracis,* the bacterium that causes the disease of anthrax, commonly exists in a dormant, sporulated form that germinates in a benign environment such as the human lymphatic system to produce the disease-causing bacillus. A gram or so of anthrax mailed to Senator Daschle was reported to have contained over one trillion spores. Ten thousand anthrax spores, if untreated, will induce death in the average person.[8] Thus, in theory, if perfectly distributed, one gram can kill millions of people. Of course, perfect distribution is unattainable[9] – but if the material were increased to a kilogram and released over an urban area, it could reasonably be expected to infect more than a hundred thousand people.

Smallpox is perhaps the most feared of agents because, unlike anthrax, it is contagious. Victims shed the virus; if uninhibited, a smallpox shedder can be expected to infect two or three others. Smallpox is also highly lethal, killing about 30 percent of those who contract it. The horror of the disease drove the world to unite in eradicating it three decades ago… yet ironically, because of our success in that noble endeavor, we find ourselves more vulnerable today to a deliberate smallpox outbreak. Much of the world population is now in the same position as the Incas when the Spanish inadvertently introduced this disease into the New World – they have no immunity (either by experience or by vaccination[10]) against the disease.[11]

A state might pursue biological weapons as a means of deterrence or coercion. Beyond the dangers of state use, however, these programs risk leakage[12] of capabilities to terrorists that are notably higher than with nuclear programs. The small size and low visibility of biological agents make them more vulnerable to theft or acquisition by bribery. Moreover, biological agents do not require substantial delivery systems. Even if terrorists do not obtain weapons from states, they may nonetheless tap into the knowledge developed in state programs to accelerate their own abilities to produce and employ biological weapons.

While biological weapons are thought of predominantly as mass casualty weapons, there are, unfortunately, other uses that may make them attractive to terrorists – in particular, their employment as narrowly targeted weapons, as weapons of mass disruption, and as campaign, rather than incident, weapons.

**Targeted weapons.** Terrorists typically have focused on particular targets of symbolic and practical value. It is sometimes thought that biological weapons, though effective mechanisms for inducing terror, are not readily targeted because winds and other uncertainties make aerosol attacks difficult to focus. Yet the anthrax letters sent in the fall of 2001 demonstrate that *B. anthracis* can be aimed at particular people or sets of people. Similarly, an aerosol bacterial or viral attack can be disseminated through the air intake of a critical building. Toxins have successfully been used as assassination weapons.[13] Even a large food supply contamination could be aimed at a relatively narrow target – for example, a military base. Foot and mouth disease or crop attacks can be aimed at a nation's economy rather than its people.

**Weapons of mass disruption.** In addition to their human toll, the anthrax letters gravely disrupted the U.S. mail system. An attack of this kind at a time tax payments are due or a continued attack that impeded all billing and payment systems would have substantial effects on the

American economy. More generally, biological weapons could be deployed as area denial weapons. The anthrax letters closed four major facilities. It took three months to return the Hart Senate Office Building to use, two years to complete clean-up of the Brentwood and Trenton postal facilities, and three years before the American Media Building in Florida was decontaminated. The total cost of these four efforts was almost $250 million.

A broader attack would be extremely disruptive. We have only a rudimentary understanding of decontamination, including how to decontaminate, how to measure what we have decontaminated, how to preserve electronic and optical equipment, how to preserve precious assets such as paper records and paintings, and, above all, "how clean is clean?" – that is, to what standard we need to decontaminate. We also have very limited assets for what is presently our most effective means of decontamination, producing and spraying chlorine dioxide gas. A meticulous analysis has calculated that with present technologies and engaging all potential assets, the cleanup of an aerosol dissemination of one kilo of *B. anthracis* over Manhattan would take 42 years.[14]

Anthrax is not alone as a contamination problem. An aerosol release of a virus such as smallpox or SARS in a subway system, tunnel or airport would have similar area denial effects with grave economic consequences. In both civilian and military contexts, we also should be concerned about biological attacks on ports, not only for their effects on people but for their effects on commerce and on the flow of military goods. In a foreign contingency, for example, 95 percent of military supplies are carried by sea. It is not uncommon for there to be only one port of debarkation abroad. That port will depend on immovable assets and on civilians who are likely to be unwilling to enter a contaminated area.

Biological weapons can also achieve mass disruption by attacks on our economic system. The damage from Cases 3 (poisoning the food supply) and 4 (attacking animals) can readily be envisioned. The 2001 British foot and mouth disease outbreak is estimated to have cost the UK on the order of $15 billion.[15] It also proved psychologically and politically disruptive; by all accounts, the government's credibility and authority suffered severely.

**Campaign terrorism.** Terrorist attacks are commonly thought of as time-bound "incidents." However traumatic the assaults on two of our embassies in Africa, on Khobar Towers and the Cole in the Middle East, or on the twin towers and the Pentagon on 9/11, when they were over, they were over. Terrorist capabilities to perpetuate those attacks were, at least for the moment, exhausted, and our abilities to respond with heightened security permitted us to resume, among other things, commercial air traffic, embassy business, use of the Pentagon, and visits by our warships to foreign ports. Subconsciously, these experiences feed an American vision of warfare generally and terrorism particularly: that others may surprise us and the effects may be traumatic, but after an attack there will be a lull, we will regroup and implement more effective protection, and in the longer term, our resilience, diversified strength, and unity will enable us to prevail.

Unfortunately, biological weapons particularly lend themselves to another less desirable paradigm: campaign terrorism rather than incident terrorism. Biological attacks are not likely to be limited by the supply of material. Supply is measured in grams and kilos. While scaling from grams to kilos typically requires moving from laboratory bench systems to more substantial, but still room-sized, production, if you can manufacture one kilo, you can manufacture many.[16] Attackers do not need substantial or very visible launch vehicles – a backpack sprayer will do. Attackers can stand at a distance, attack and then relocate across considerable distances. We are not likely to be aware of an attack until several hours (assuming that sensors detect it) or even several days (if we have to await manifestations of infection) after it is launched. Attackers are therefore likely to be able to attack, move, reload, and attack again, and again, and again. Without warning or instantaneous alert systems, we have no significant defenses against this mode of assault. On the morning of 9/11 we could shut down the air transport system. We cannot shut down the atmosphere.

Put more colloquially, when we think in "incident" terms, we envision a competition rather like football. The other side may run a devastating play, but then we expect that we will huddle and take the offense ourselves. Unfortunately, bioterrorism, more than any other form of terror, is likely to be more like what the rest of the world calls "football" and we call "soccer." It admits of no time out and of no distinct phases of offense and defense; rather it is a continuous flow. This will, of course, be no game, but rather a particularly brutal form of battering, without remission.

Once realized, this ability to "reload"[17] and attack repeatedly with biological weapons is likely to be very attractive to terrorists. It will give them a supreme opportunity to hold us hostage. A kilo of anthrax used first in Washington, then in Detroit, then in San Francisco, with subsequent threats to use it elsewhere (or recurrently in these places) is likely to panic the nation. Published statements suggest that our antibiotic stocks are limited and anthrax vaccine supplies more so. Even if the vaccine were instantly available (an unrealistic assumption), in unlimited supply (an equally unrealistic assumption), all our population could take it (ignoring children, pregnant women, *et. al.*), and it were universally effective for those who took it (this is not the case), it still would take some 35 days for the vaccine to be effective.[18] Against this backdrop, policy makers should be focused on the factors that affect the abilities of terrorists to develop, proliferate, or use biological weapons[19]

It is difficult to assess and convey the challenges associated with developing biological weapons because discussion and experimentation are inhibited by our desire to avoid educating states and terrorists. We are less knowledgeable than we are about nuclear, chemical and conventional weapons because since 1969, the United States has quite properly foresworn an offensive program.[20] Our pre-1969 work was undertaken for military ends with precision, quality assurance, safety and other requirements that would be unlikely to apply to other states, not to mention terrorist organizations. Certainly new technologies that enable biological weapons have emerged since the era of the previous offensive program. We therefore have a suspect base of experience from which to extrapolate.

In the main, though, the "difficulty in assessing difficulty" is that the range of possible biological weapons is vast, the routes to success are varied, and the field is dynamic. As the science rapidly advances, today's Nobel Prize complexity becomes tomorrow's graduate work. If generalizations are suspect, we can, nonetheless, gain some perspective by focusing on the five reference cases and noting five problems that affect them all. An aspiring biological terrorist must (a) acquire a pathogen; (b) amplify it (that is, grow it in substantial quantity with adequate virulence); (c) be able to weaponize it (that is, stabilize it in a form that will permit both interim storage and ultimate effective release); (d) field test it; and (e) disperse it.

## How Hard Are These Tasks?

**Acquisition** is modestly, but not dramatically, difficult. Three simple routes are to buy, steal, or harvest a pathogen. *B. anthracis, Clostridium botulinum* (the organism that produces botulinum toxin), and various strains of the foot and mouth virus are available for purchase because widespread research is relevant to constraining natural occurrences of the diseases they cause. Smallpox is known to be kept only at a facility in Russia and at the CDC in the United States. Access for research is tightly controlled.

Restrictions on the purchase of the available pathogens have tightened over the last few years.[21] Responsible sellers examine the credentials and credibility of buyers, but commerce in many pathogens is widespread; front organizations can be created and sympathetic scientists (or underpaid alumni of the Soviet program) can be conduits. Microbiologists and veterinarians are notorious for maintaining extensive, badly inventoried and poorly secured samples of pathogens. Experts acknowledge that smallpox might be found in a laboratory anywhere in the world.

To appreciate some quantitative sense of the problem, consider that some 1,500 facilities in the United States are estimated to stock pathogens.[22] A "putative listing" by Western experts of "biotechnology entities" in the former Soviet Union has well over 500 entries.[23] SARS – no longer known to exist in human populations – is estimated to be preserved in 175 laboratories around the world. Harvesting a pathogen is less visible than buying or stealing, and opportunities are prevalent. All pathogens (except smallpox) are extant, and particularly so in parts of the world that are associated with terrorists.[24]

Of course, there are complications. A strain may be available but not potent, or it may be insufficiently concentrated or difficult to collect. A would-be procurer may be deterred by his own vulnerability, and even a highly motivated group may run into difficulties. Aum Shinrikyo, for example, attempted to develop biological weapons before the group dispersed Sarin on the Tokyo subway system in March of 1995. They are reported to have dispatched members to Africa to attempt to collect samples of Ebola, but without success. They then ordered an anthrax strain from a Japanese type culture organization. Their order was filled without complication, but the cult had mistakenly requested a benign veterinary vaccination strain.[25] As a result, when they mounted a device to aerosolize and spray anthrax slurry from the rooftop of their offices in Northern Japan, they succeeded in infecting no one, though neighbors complained about the smell.[26]

On the other hand, most experts think that a potent sample of foot and mouth viruses – endemic in many parts of the world – can be obtained simply by wiping a cloth under an infected cow's nose.

Case X opportunities for states[27] or terrorists to modify existing pathogens or to create their own "super pathogens" are proliferating.[28] At the simplest level, antibiotic resistant anthrax can be created by culturing naturally occurring samples, spreading an antibiotic over the plate, and selecting only for bacteria that manifest resistance. By repeating this process over a number of generations (anthrax takes about 30 minutes to divide and produce a new generation under good culturing conditions) antibiotic resistant pathogens can be obtained.

Contemporary graduate students transfer genes between bacteria as a routine part of their education. Cutting-edge techniques in the most sophisticated U.S. labs include gene shuffling – randomly redistributing genes among large numbers of specimens, followed by selecting among them for a desired characteristic, then random shuffling among the agents that exhibit this characteristic, further selecting from among this group, further shuffling, and so on. By molecular breeding a scientist can, in weeks, induce processes that would normally take millennia, and achieve unpredictable outcomes.[29]

**Amplification** is at about the same level of complexity/simplicity as acquisition, with similar variability. Modern pharmacology grew out of the brewing and dyeing industries. A number of related industries, particularly makers of biological insecticides, have adapted fermenting tools and dissemination technologies to their own ends. Bacterial pathogens can be produced with the same techniques.

Bench-level production, generating a few liters of liquid agent or a few grams of dry agent every week, would be familiar to those trained in biology. The necessary equipment would also be easy to obtain at costs in the range of a few tens of thousands of dollars. Large fermenters are controlled for export, but until recently fermenters at or below 100 liters were obtainable without restriction. (Now the restrictions reach to 20 liters, still substantial enough to produce significant quantities of agent.[30]) Related equipment, such as sterilizers to avoid contamination and centrifuges to separate an agent from the medium in which it is grown, is unregulated and inexpensive. Most bacteria can be amplified by a single perpetrator with craftsman level skills.

Small-scale production lines can be proliferated and their product stored to yield substantial quantities of agent. Ten fully operating twenty-gram production lines might yield a kilo of agent within two months, but multiplying production lines demands more manpower, entails greater expense, increases complications, provokes more visibility and incurs more risks of accident and error. Raising production volumes through larger and more sophisticated equipment would be more attractive, but it requires larger, more expensive, more visible, and more complicated equipment and supporting infrastructure. Processes that would produce a kilogram of material in a single batch would demand mechanical and engineering skills as well as biological expertise. Unfortunately, these skills are not particularly subtle and the equipment is widely available on used material markets at prices in the hundreds of thousands of dollars.[31]

Techniques for proliferating viruses are also well known. Whereas bacteria is supported in protein cultures, viruses typically require a medium of living cells. Smallpox for example, may be grown in eggs; the eggs are then mashed in a blender and the product purified. Generations of medical students learned to do this before smallpox was eradicated. Alternatively, viruses can be grown in, and harvested from, animals or tissue cultures.

**Weaponization** would be the most difficult and time consuming step in the process. While collection and purification knowledge is widespread among ordinary scientists, weaponization is obviously a military subject and much of the knowledge that surrounds it is classified.

The central challenge for an aerosol attack would be to produce a pathogen formulation in sizes that would be within the human respiratory range and could be reliably stored,[32] handled, and spread as a stable aerosol rather than clump and fall to the ground. Mastering these somewhat contradictory requirements is tricky. The challenge becomes greater as attackers seek higher concentrations of agent and higher efficiency in dissemination.[33] A terrorist or state that would disperse anthrax, smallpox or similar agents might be satisfied with an inefficient and awkward, but more easily produced, liquid medium; it might aim for a dry powder that would be more difficult to refine, but easier to store and transport; or it might hedge its bets by pursuing both routes.

If a powder is produced, there will also be challenges in keeping too much of the resulting product from floating away. Open literature discusses techniques such as adding silica or research-grade graphite as an effective means to this end. Micro-encapsulation (a more sophisticated technique that applies wet-form preparations) and charge neutralization are also often discussed, but these technologies demand more equipment and skill.

Though they pose substantial challenges, the evidence suggests that problems of weaponization can be solved for a number of agents and/or that these problems can be circumvented by using means of dispersion that are less challenging than an aerosol attack. Several such methods are noted below in the section on dispersion.

**Field testing** was a substantial focus of energy and dollars for our offensive biological weapons program and for the Russians. The Japanese use of pathogens against Chinese populations during World War II may predominantly have been for test purposes. Testing would be a substantial difficulty for a less endowed state, attempting to act secretly, and it would be a particular challenge for terrorists. Any Case X pathogen will obviously require more testing than an established pathogen.

Today, states and terrorist groups may choose to test by cruder methods or not at all. Aum Shinrikyo apparently tested chemical weapons against sheep in Australia and then, as noted, sprayed anthrax from the rooftop of its offices in Japan. A terrorist could decide to release an untested or rudimentarily tested pathogen on a target population and observe the consequences. (If the anthrax letters of 2001 were not the work of a "super patriot" as suggested by the FBI, they may have had this purpose.) The absence of testing introduces uncertainties, but does not appear to pose fundamental difficulties.

**Dispersion** by physical contact is relatively straightforward. It can be accomplished, for example, by transferring foot and mouth virus from one cow to another by rubbing cloth under the nostrils of each in succession or by impregnating blankets with smallpox. Aerosol dissemination potentially infects greater numbers, faster, but is more complex. Aerial dissemination is now a common practice for crops, but this involves large droplet sizes dispersed over open fields.

Dispersion control for human targets is notably more difficult: the targets are often in urban areas and particles that are readily inhaled by humans are mainly in the one to five micron range – smaller than those dispersed in a normal crop dusting effort. Some testing of dispersion methods will be required. Aum had difficulty running liquid anthrax slurry through a spray device – the system clogged. If weaponization problems have been solved, however, aerosol dispersion is not likely to pose a significant challenge. For an adequately weaponized agent (especially a powder) many sources in the open literature suggest that simple backpack sprayers will be sufficient.[34]

A dispersed biological agent would be vulnerable to winds and degradation from sunlight. Anthrax survives in summer sunlight for only two and a half hours.[35] Smallpox would degrade even faster. Here, too, however, there is a range of possible solutions. At the most sophisticated level, coatings will inhibit degradation. More simply, the problem may be attenuated by using an outdoor aerosol at night and only under desired weather conditions.

Alternatively, an attacker may circumvent weather concerns by dispersing an agent through a heating or air conditioning system. Within a subway system, the piston effect of trains will drive dispersion while protecting from environmental influences. As the Indian victims of British smallpox epidemic found, blankets can spread the disease when impregnated with virus from smallpox scabs. Humans can be intentional or unwitting carriers as well. If botulinum can be infiltrated into a central mixing vat, a producer of beer will unwittingly effect distribution on behalf of an attacker.

The highly contagious foot and mouth disease captured, as described above, by wiping a cloth under a cow's nose, can be disseminated by wiping the same cloth under another cow's nose. The virus, which is the most contagious known, will then move with winds and with the movement of the cattle involved. (Livestock in a modern economy are extraordinarily mobile and concentrated.)

Three overarching conclusions emerge from this analysis:

First, there is a large range of biological weapons; it is too facile to speak generally of their simplicity or complexity of development. It is altogether too easy to harvest some agents and apply them to some uses; other uses require some craftsman-like skills for amplification and perhaps adaptation; some catastrophic opportunities with aerosolized weapons require substantial effort and absent classified military knowledge will take considerable trial and error before they are likely to be mastered.

**Only a thin wall of terrorist ignorance and inexperience now protects us.**

Second, notwithstanding the above, it seems fair to say that biological weapons as they are now understood (for example in Cases 1-4) fall between conventional explosives and nuclear weapons. On one hand, the technologies have not yet been integrated and weaponization mastered by substantial numbers of terrorists the way explosives have. On the other hand, it is much easier and cheaper to master and covertly exercise these skills than it is with nuclear weapons. Over time, the skills associated with biological weapons are likely to be acquired and exercised, first in more rudimentary forms and then with increasing sophistication. Only a thin wall of terrorist ignorance and inexperience now protects us.

Third, there is a frightening category of biological weapons – those that do not exist in nature – in the wings. The ability to generate these Case X weapons is proliferating with the expansion and spread of biological knowledge and biotechnology, and their diversity will make it harder to predict and harder to defend against their use than against pathogens that exist in nature. Preparing for them will be yet more difficult and more dangerous than preparing for nuclear weapons.

## Our Ability to Limit Proliferation and Development of Biological Weapons

Confronted by weapons of mass destruction, a wise country pursues non-proliferation as a part of its repertoire of defensive steps. World efforts to prevent nuclear proliferation have been difficult, but for six decades they have substantially constrained the spread of these weapons. We must make similar efforts with respect to illegitimate uses of biotechnology – attempting to control pathogens, equipment, people, and the pursuit or publication of certain kinds of knowledge.

Unfortunately, the principal international agreement in this respect, the 1972 Biological Weapons Convention,[36] focuses on state programs and has no functional force. The BWC does not limit the flow of pathogens or equipment and it makes no significant effort to regulate research. The three and a half page document simply declares[37] that the signatory nations undertake "never in any circumstances to develop, produce, stockpile, or otherwise acquire and retain" biological weapons (Article I); that they will destroy existing stockpiles (Article II); that they foreswear helping others to develop such weapons (Article III); and that they will not permit others to develop such weapons in their territories (Article IV). Breaches of these commitments are subject to complaint to the UN Security Council (Article VI). A 2001 attempt to begin to provide teeth for the Convention by establishing monitoring procedures was rejected by the United States and others on the grounds that it would be ineffective, while potentially damaging national security and permitting theft of intellectual property.[38]

Clearly, the United States and the community of nations can achieve more to inhibit terrorist access to biological weapons than we have so far through the BWC. There is real value in initiatives that increase proliferators' risks of detection, multiply their obstacles, and raise their costs. However, our non-proliferation initiatives must be accompanied by a clear-eyed view of the likely limits of our success. Unfortunately, the relative simplicity of the five steps described above and the diversity of routes through which they may be accomplished suggests that, though proliferation of biological weapons may be constrained and complicated, non-proliferation initiatives will likely fail against a determined and resourceful adversary.

**World efforts to prevent nuclear proliferation have been difficult, but for six decades they have substantially constrained the spread of these weapons. We must make similar efforts with respect to illegitimate uses of biotechnology.**

**Pathogens and Equipment.** Some useful steps have been taken to limit the opportunities for purchase and theft of pathogens. These raise the bar, but no one believes that they create very imposing barriers.[39] Unfortunately, equipment is similarly accessible.

Some considerable effort has gone into export controls, principally through the so-called Australia Group.[40] The 34 states participating in this effort enforce export restrictions on fermenters, sequencing equipment, pathogens, encapsulation technologies and scores of other items. These efforts are useful, but only modestly effective. One advocate of these controls likens the task to gun control in the United States.[41] The analogy is telling, not only with respect to the magnitude of the task, but also with regard to its likely success. Efforts to license and control equipment and pathogens seem at best likely to capture a small number of potential users and modestly raise the risks and costs for others.[42] This is worth doing, but it should be with the recognition that the supply of all relevant equipment is too extensive and already too distributed to be powerfully constrained. Domestic dual-use chemical, pharmaceutical, agricultural, brewing and academic research and training laboratories provide ample sources of supply with low visibility, especially for used equipment that is exchanged in unregulated markets.

**People.** There is a high enough level of sophistication in collection, amplification, testing, dispersion, and, particularly, in weaponization to make it likely that terrorists interested even in natural pathogens will attempt to recruit experts. In particular, any effort to produce Case X agents will demand experienced and skilled professionals.

Unfortunately, the number of people who have the relevant skills is large and growing.[43] Analysts and policy makers should, I think, distinguish between two categories: "Weaponeers" who have substantial experience with biological weapons in state programs and "The Broadly Skilled" scientists and technicians who have relevant training but no experience applying it to biological weapons. Weaponeers include those whose activities are defensive; they will know less then participants in offensive programs, but much more than generalists. The Broadly Skilled can be as, or more, sophisticated than the Weaponeers, but they will pursue more false paths, make more errors, and therefore need more time and money – implying greater risks of failure, self-infection, and/or capture – than the Weaponeers.[44]

As an order of magnitude assessment,[45] I would suggest that the first class might be between one and ten thousand people.[46] A majority of this group comes from the Soviet program, but significant numbers also will be Americans, British, Iraqis, and alumni of, or present participants in, unacknowledged programs. (I include our own and allied programs in calculating the pool of potential terrorists because terrorism is not simply a foreign phenomenon. A reported FBI theory is that the anthrax letter perpetrator is an American drawing material and expertise from our program. The primary previous example of bioterrorism on American soil was perpetrated by an Oregon-based religious group.[47] And, of course, Unabomber Theodore Kaczynski and Timothy McVeigh provide striking examples of American-bred terrorism.)

It is plausible for us to co-opt and/or monitor Weaponeers to the extent that we know and have access to them. This is, and should be, one of our most effective means of controlling non-proliferation. Quite wisely, our efforts have focused on the former Soviet Union. Our Cooperative Threat Reduction Program (created in legislation proposed by Senators Nunn and Lugar) has employed nearly 50,000 former nuclear, biological, chemical, and missile scientists in the former Soviet Union.[48] Many of the biologists are researchers at Russian institutes on vaccines and drugs intended to protect people, animals and crops. An imaginative new Department of Defense initiative under CTR has employed a number of scientists in a human and animal health surveillance network in Georgia, Kazakhstan and Uzbekistan.[49] The State Department's Office of Proliferation Threat Reduction similarly employs former Weaponeers in a Russian flu (including avian influenza) surveillance network. Using a one-time $30 million appropriation, with $5-6 million annual operating funds, this office has also vigorously begun to back business collaborations between "former Soviet biological weapons scientists" and U.S. industrial partners, and approximately forty drug and vaccine projects have been established so far.[50]

These programs offer high rewards relative to their costs. A senior Russian scientist earns approximately $2,500 a year. Taking administrative and infrastructure costs and inefficiencies into account, a supporting program might cost $10,000 per scientist. Less than $100 million a year could accordingly buy us substantial relationships with as many of the foreign Weaponeers as might be found and engaged. It should be stressed, however, that the important variable is "relationships." An American payment to a former Weaponeer may diminish that individual's propensity to avoid working on a weapons program, but it doesn't guarantee it. Some may find bribes from terrorists or states too attractive to resist. Others may use our funds to continue their old activities.[51] Our best gain from these programs is not to win the compliance of all, but rather to establish deep relationships with a substantial number so that these in turn will police their colleagues and if necessary advise us of questionable individuals and activities. There is evidence from the Russian program that this is achievable, though of course imperfectly so.[52]

More troublesome is the fact that though this model works for the former Soviet Union, it will apply less effectively to more controlled societies, like China, and hardly at all to essentially closed societies like Iran and the extreme case of North Korea. At best, the several thousand individuals possibly engaged in programs in those countries should be monitored from a distance. Unfortunately, our efforts in that regard are likely to generate, at best, a few successes (which should be much valued) and many failures.[53]

The intrinsic difficulty of this effort is likely to be compounded by our own resource and bureaucratic problems. The number of intelligence agency employees who speak Farsi or Mandarin (not to mention Arabic or Korean) and understand biology will be severely limited. Careers using those rare skills in our intelligence system are not likely to be rewarding. Our systems are keyed to recognizing and advancing those who report actionable intelligence. A lifetime of surveying a facility or collection of scientists in the developing world may never yield anything actionable.

When we move from the thousands of Weaponeers to The Broadly Skilled, the limits of the tracking strategy become yet more apparent. As a very rough approximation, I would suggest that this group encompasses more than a million people – at least two and perhaps three orders of magnitude larger than the Weaponeers.[54] Members of this group may become dangerous by obtaining expertise from Weaponeers. Unfortunately, they can also develop dangerous expertise through their own trial and error. The great majority of them, of course, would not undertake this work and a number who did would not be successful, but it seems likely that, over time, broadly skilled individuals equipped with modest laboratory equipment could develop biological weapons. They could do this in state programs, as members of terrorist groups, or simply as individuals.[55] If the Unabomber had been a biologist instead of a mathematician, he might well have mailed pathogens instead of pipe bombs.[56] Worse still, our experience with bombs made from conventional explosives suggests that the success of a very few who are members of groups, rather than hermits like the Unabomber, will proliferate as they train others and provide recipes to them.

Our strategy for dampening the risks from The Broadly Skilled must engage our science community and encourage it to interact heavily with colleagues in developing countries, to use moral suasion to stigmatize work on biological weapons, and to report what appear to be instances of such work. Ultimately, our success or failure will be most affected by the extent to which other nations and their scientists also stigmatize and report on this research.[57] There is a role for the Biological Weapons Convention in this context. This international agreement could, as has been recommended by several commentators[58] and nations, including the United States, commit member states to criminalize research and development directed to improper ends. In pursuing these efforts, however, we should recognize that our present approach of denying visas to third world scientists is precisely wrong. The costs to our relationships with future colleagues in foreign countries outweigh the gains we may achieve by attempting to keep knowledge from some who may misuse it.

**Consequence management should be perceived not only as a means of limiting damage and rapidly restoring normalcy, but also as a mechanism of dissuasion.**

**The Pursuit and Publication of Knowledge.** The biological revolution initiated by Watson and Crick a half-century ago cannot, and should not, be stopped. It leads, however, to the intensification of the threat from biological weapons.

We can make, and are making, efforts to control this knowledge.[59] Efforts in the United States and a few other countries were particularly stimulated by the publication of research results demonstrating abilities to synthesize the polio virus and to create pox viruses that might circumvent vaccines.[60] We are now introducing controls on laboratory experiments.[61] These are useful,[62] but obviously do not apply on a global basis.[63] Nor do they do more than diminish one route that might lead to biological weapons.[64] Worst of all, from the standpoint of proliferation, the fundamentals of this knowledge are already widespread and legitimately proliferating. They are the basis of pharmaceutical, biotech, medical and agricultural progress. We can channel some activities, but we must recognize that the river of knowledge is already at flood stage and cannot be drained.[65]

As a result, I believe that alongside non-proliferation activities, the United States must urgently prepare to manage the consequences and recovery from biological attacks, even though this preparation was not a materially successful part of our approach to nuclear weaponry.[66]

Consequence management should be perceived not only as a means of limiting damage and rapidly restoring normalcy, but also as a mechanism of dissuasion. Biological weapons have disadvantages: They are unfamiliar, may rebound against some constituencies (particularly if contagious), and will be viewed by some as overstepping "red line" boundaries of acceptable warfare. The history of weapons use suggests, unfortunately, that someone, someday will use them.

If our defensive responses are disorganized, ineffective or divisive and undermine confidence in government, then the incentives for copy-cat attacks will rise. If, conversely, we are prepared and effective, and an attack emphasizes the qualities of our government and the unity of our population, then the incentives to attack again in that manner will be dramatically reduced.

## Endnotes

1 I am very grateful to Siddharth Mohandas for fine research assistance, to Seth Carrus for an exceptionally productive review of this paper, and to Roger Breeze, Don Burke, Michael Callahan, Jerry Epstein, David Franz, Brian Jones, Bob Kadlec, Terry Leighton, Judy Miller, Bill Patrick, Jason Rao, Amy Smithson, Steve Prior, Tara O'Toole, Jerry Warner, Andy Weber, Larry Wein, Dean Wilkening, and Ray Zilinskas for comments on this paper as well as for basic education on the subject. This paper would not have been written without the catalyzing effect of Kurt Campbell's support, imagination and energy in the Aspen Strategy Group and at CSIS.

2 I recommended using these reference cases, in a slightly different form, in Richard Danzig, "Catastrophic Bioterrorism: What Is To Be Done?" (GPO: 2003)

3 A toxin is a poison produced by natural sources. Toxins are commonly treated as biological weapons, but they also have the attributes of chemical weapons and are regulated by the Chemical Weapons Convention as well as by the Biological and Toxin Weapons Convention.

4 While adopting the reference cases from Danzig, op cit., the Science and Technology Directorate of the Department of Homeland Security renamed Case 5, "Case X." I think this is an improvement and will use that term here. For a recent survey of Case X possibilities see Mark Wheelis, "Will the New Biology Lead to New Weapons?" in *Arms Control Today* (July-August, 2004). Dr. Wheelis, a microbiologist, sees such weapons as arising from "new technologies" including "genomics, proteomics, micro-array technology, high-throughput screening techniques, combinatorial methods in chemistry and biology, site-specific mutagenesis, knock-out mice, and many others."

5 See generally, Erhard Geissler (ed.) *Biological and Toxin Weapons: Research, Development and Use from the Middle Ages to 1945* and Jeanne Guillemin, *Biological Weapons: From the Invention of State-Sponsored Programs to Contemporary Bioterrorism* (forthcoming, Columbia University Press). The extent of Japan's use of this weapon against China is difficult to determine, but as more evidence as has been uncovered, it has led to increasing estimates of deaths. Daniel Barenblatt, *A Plague Upon Humanity* (2003) writes that "As of 2002, historical researchers in China estimated the number of people killed by Japanese germ warfare and human experiments to be approximately 580,000. This is the figure that was presented and mutually agreed upon at the International Symposium on the Crimes of Bacteriological Warfare, a conference on the subject … attended by scholars and investigative journalists …." (p. xii). Barenblatt argues that this figure is "only a preliminary accounting." (Id.) More convincing is the documentation of a number of incidents. Sheldon H. Harris, *Factories of Death* (rev. ed. 2002) reviews, among many examples, a five-month campaign against the treaty port of Ningbo. In 1940, 1,000 people were infected and 500 people died from cholera, typhus and plague. (Id., p. 102). "Most alarming is that the diseases … unleashed in the summer and fall of 1940, and subsequently in 1941 and 1942, had long-term effects. Plague ravaged Ningbo and nearby communities in 1941, 1946, and 1947. Occasional outbreaks occurred in the region as late as 1959." (Id. p. 103).

6 A summary of the Iraqi disclosures can be found at http://www.fas.org/nuke/guide/iraq/bw/unscom.html. UNSCOM monitoring efforts and the defection of Saddam's son-in-law in 1995 revealed subsequent further activity. UNSCOM report, S/1999/94, 29 January 1999 at http://www.un.org/Depts/unscom/s99-94.html.

7 The Henry L. Stimson Center reports that "according to the US government, 13 nations currently have active biological weapons programs" and comments on nine of those programs. See "Biological Weapons Proliferation Concerns" at www.stimson.org/cbw.

8 This, like many other scientific assertions about bioterror weapons is subject to debate and certainly has a margin of error. For a summary of the evidence and alternative views, see Thomas V. Inglesby et al., "Anthrax as a Biological Weapon, 2002: Updated Recommendations for Management," *Journal of the American Medical Association* 287, no. 17 (May 1, 2002) pp. 2236-2252.

9 In 1979, an accidental release in Sverdlovsk infected at least 88 people, killing 64. The best present estimate is that the release was on the order of a gram. Dean Wilkening, unpublished brief, 2004. Wilkening concludes that the release may have been as small as .025 milligrams. Some authorities believe the release was larger – on the order of 50 grams.

10 There is also uncertainty about the residual benefits for those who were vaccinated decades ago.

11 If we succeed in eradicating polio, we are likely to create the same vulnerability to terrorism with this virus as we have to smallpox.

12 I use the term "leakage" to emphasize that states seem more likely to inadvertently lose control of these agents than they are to intentionally place them in the hands of terrorists. Indeed, the apparently dominant FBI theory about the 2001 anthrax letter attacks is that the attacker stole a weaponized agent from one of our (or our allies') labs. A state could provide agents to proxy terrorist groups, hoping particularly to benefit from the difficulty of attributing biological weapons to a specific source. The ability to "reload" described below would, however, place such great power in the hands of a group that it may be doubted whether a state would be willing to assume that risk.

13 In 1978, Bulgarian dissident Georgi Markov was killed after he was injected with a tiny ricin-filled pellet while walking on a London street; http://news.bbc.co.uk/1/hi/uk/2636459.stm. From 1981 to 1995, "Project Coast," a South African program researching chemical and bioterror weapons was focused on agents "intended to be used for assassination and crowd control." Chandre Gould and Peter Folb, *Project Coast: Apartheid's Chemical and Biologcal Warfare Programme* (Geneva: United Nations Institute for Disarmament Research, 2002) p. 2. See pp. 159-168 for a catalog of "incidents of poisoning" associated with the program.

14 Larry Wein. Unpublished manuscript. 2004.

15 The British government cites a figure of about eight billion pounds in combined damage to agriculture and tourism; see Department for Environment, Food and Rural Affairs and Department for Culture, Media and Sport, "Economic Cost of Foot and Mouth Disease in the UK: A Joint Working Paper," March 2002. Official and third party reports are unanimous in their view that these events could have been better handled. Accordingly, these costs may be at the high end.

16 The weaponization process is described below. In general, moving from grams to kilograms requires complementing modest biological skills with modest mechanical skills.

17 I applied this label in Danzig, op cit.

18 Some experts think this generally accepted estimate is too prolonged and that immunity might be achieved in 25 days. Further evidence on this point is being pursued. There is also not much evidence as to how efficacious the vaccine would be for very large populations in heavily contaminated environments. I note also that the present vaccine, as licensed, requires annual boosters after an initial six shot regimen.

19 This discussion would apply as well to the ability of states to develop biological weapons.

20 Our commitment to the Biological Weapons Convention also complicates our conducting "proof of principle" experiments that might demonstrate the ease or difficulty associated with production processes.

21 See footnote 34 below.

22 Jonathan Tucker, *Biosecurity: Limiting Terrorist Access to Deadly Pathogens* (United States Institute of Peace, 2003) p. 21.

23 Ivor Gutmanis, "FSU Biotechnology Entities: Putative Listing, 1998-2002" (Hobe Corporation, September 2003).

24 Thus, for example, as this paper was submitted, news reports carried an account of seven people hospitalized from anthrax in Kazakhstan; http://news.scotsman.com/latest.cfm?id=3155820.

25 Paul Keim et.al., "Moleculare Investigation of the Aum Shinrikyo Anthrax Release in Kameido, Japan, *Journal of Clinical Microbiology* 39, no. 13 (December 2001) pp. 4566-4567.

26 Hiroshi Takashi et al., "*Bacillus anthracis* Incident, Kameido, Tokyo, 1993," *Emerging Infectious Diseases* 10, no. 1 (January 2004) pp. 117-120.

27 The Soviet Union was intensely committed to this research even as its economy imploded.

28 These same techniques can be used to synthesize agents that already exist in nature. It is hard to see, however, why attackers would trouble to acquire natural agents by this route rather than by purchase, harvesting, or theft. Smallpox may be an exceptional case because it is eradicated and known samples are tightly controlled.

29 Recently, an alarming natural evolution was reported when samples from pneumonia patients disclosed that the protective antigen toxin from *B. anthracis* was being produced by a different bacterium, *Bacillus cereus.* Alex R. Hoffmaster, et al., "Identification of anthrax toxin genes in a *Bacillus cereus* associated with an illness resembling inhalation anthrax," *Proceedings of the National Academy of Sciences* 101, no. 22 (June 1, 2004) pp. 8449-8454.

30 Arms Control Association, "The Australia Group at a Glance," September 2003. http://www.armscontrol.org/factsheets/australiagroup.asp.

31 Large national programs (the Soviet Union was the leading example) have historically produced tons of agent in large fermenters that ran continuously for months. In a well-documented example, the U.S. Defense Department noted that ten 5,000 gallon fermenters were operated at the former anthrax facility in Stepnogorsk, Kazakhstan. It estimated that under wartime mobilization conditions, the facility would produce 300 metric tons of weaponized anthrax in eight months. As suggested above, a terrorist would need nowhere near such a supply. (It is doubtful that the Soviet Union had use for it!) Andy Weber, "Cooperative Threat Reduction: Biological Weapons Proliferation Prevention Program," Briefing Presented in Stockholm, June 2004 and subsequent communications with the author. The capability has now been dismantled. Large numbers of abandoned fermenters may be observed at former Soviet facilities with little or no security protection.

32 Different agents are differently sensitive to variations in heat and humidity. Most degrade if separated from the nutrition that sustains them.

33 The high concentration of spores in the anthrax powder sent to Senator Daschle suggests that the perpetrator possessed remarkable scientific knowledge and technical skill or obtained the material from a program that had these attributes. Dana Shea, in a Congressional Research Service Report, "Small Scale Terrorist Attacks Using Chemical and Biological Agents: An Assessment Framework and Preliminary Comparisons" (May 20, 2004, Order Code RL 32391) pp. CRS-11-16 usefully provides flow charts and a discussion contrasting the lower demands on terrorists from producing smaller quantities of lower quality agent as compared with more ambitious military programs. A chart (on pp. 24-25) provides an assessment of the ease of acquisition and dissemination, as well as other factors, for different biological agents.

34 At a more sophisticated level, particle sprayers are produced in high volume for use in industrial coatings.

35 Takashi, op. cit., p. 119.

36 "Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and Their Destruction." The document includes 15 articles, but those not described in this paragraph are essentially procedural.

37 By contrast, Amy Smithson notes that the Chemical Weapons Convention is 46 pages, with over 140 pages of annexes. "Compliance Through Science: US Pharmaceutical Industry Experts on a Strengthened Bioweapons Nonproliferation Regime," Henry L. Stimson Center, 2002, p.8, fn. 33.

38 An international group of verification experts arrived at an opposite judgment. It concluded that state programs would be inhibited by a requirement for declaration of programs and facilities working in related areas (e.g., vaccines) coupled with short-notice inspections to assess the accuracy of the declarations. See United Nations, *Special Conference of the State Parties to the Convention on the Prohibition of Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction: Final Report* (Document BWC/SPCONF/1, 1994). However, whether significant or not in restraining state action, these steps would not directly address the risks of weapons development by terrorists.

39 A neo-Nazi's 1995 purchase under false pretenses of vials of the pathogen that causes plague prompted a 1996

statute that directed the Department of Health and Human Services to regulate transfers of dangerous biological agents. A year ago, 335 facilities were registered. Tucker, op. cit. p. 19, citing Stephen Morse, U.S. Centers for Disease Control, "The New Select Agent Regulation" (presentation at the ABSA conference on "Biosecurity: Challenges and Applied Solutions for Our Future Needs," Alexandria, VA, April 22, 2003). The anthrax letter attacks prompted a strengthening of these provisions with the Bioterrorism Preparedness Act, enacted in June of 2002, that required all users of pathogens to develop inventories of these agents, lists of those with access to these pathogens, and security measures to reduce the risk of improper access. Op. cit. p. 21. Tucker calculates that "an estimated total of 1,469 facilities will be affected by the new biosecurity regulations." Op cit. p. 21. Section 817 of the USA Patriot Act makes it a crime for a person knowingly to possess a biological agent or delivery system without "a prophylactic, protective, bona fide research, or other peaceful purpose." Facilities abroad remain less regulated. DTRA Nunn-Lugar expenditures have bought increased physical security in the former Soviet Union. It should be noted, though, that while these efforts limit the ability of terrorists to break in, they are only marginally effective in diminishing the ability of scientists to carry pathogens out of their laboratories. A former Director of our Plum Island Animal Disease Center notes "it has been known for 30 years that those working in the labs can take foot and mouth virus home in their noses and that live virus can be recovered for 36 hours afterwards. This is the basis for denying workers the ability to have susceptible livestock at home, and to visit a farm, a circus or a zoo. So what are the guards guarding?" Personal communication from Roger Breeze to the author, July 7, 2004. Probably the most useful activity in this regard is to concentrate dangerous pathogens in a limited number of facilities with well-controlled access.

40 The Australia Group, founded in 1985 to coordinate regulation of precursors for chemical weapons, expanded its focus to include biotechnology in 1990. It is an informal effort that aims to coordinate national efforts. For general information, see www.australiagroup.net.

41 Robert Wright, "A Real War on Terrorism," Part 8, September 12, 2002, *Slate*, http://slate.msn.com/id/2070210/entry/2070799. Regarding control mechanisms, see also Jonathan Tucker, op. cit.

42 A conversation with an administrator of the U.S. controls yielded an estimate that there were some 1,500 biology related export applications per year, of which roughly 80 percent were approved, 15 percent returned with no action, and 5 percent rejected. Telephone conversation of Siddharth Mohandas with Mark Sagrans, Export Policy Analyst, Chemical and Biological Controls Division, Department of Commerce, June 28, 2004.

43 How many are there? Though this question is fundamental to a theory of non-proliferation, I cannot identify any place where it has been substantially addressed.

44 This difference is material. Terrorist groups can be thought of as investors with limited capital and a focus on rewards within the next few years. The CIA is reported to have assessed al Qaeda's budget at some $30 million per year. National Commission on Terrorist Attacks Upon the United States, "Overview of the Enemy," Staff Statement No.15, p.11. For an organization at this level, access to a Weaponeer makes pursuit of a biological weapon much more attractive because it lowers the likely cost and time of the effort and increases the apparent probability of success.

45 Hopefully, the back of the envelope first assessments offered here will stimulate a sounder calculation of the numbers of "Weaponeers" and of the "Broadly Skilled."

46 My aim here is not to claim some spurious precision but to offer an estimate that suggests the order of magnitude of the problem. Higher or lower numbers could be supported. The Federation of American Scientists has written: "At its peak, the former Soviet Union had the world's largest biological warfare program, with somewhere between 25,000 and 32,000 people employed in a network of 20 to 30 military and civilian laboratories and research institutions. An additional 10,000 or so worked in Defense Ministry bioweapons laboratories. According to other estimates, at least 47 labs and test facilities were scattered across Russia, employing more than 40,000 workers, 9,000 of whom were scientists. Between 1,000 to 2,000 of those scientists were experts on deadly pathogens. Biopreparat suffered dramatic downsizing after the dissolution of the Soviet Union in 1991, with more than half its scientific staff departing, many of whom left Russia for more sophisticated laboratories of the West." http://www.fas.org/nuke/guide/russia/agency/bw.htm.

47 See the description of the September 1984 food contamination attacks of the Rajneeshee cult in Miller, Judith, Stephen Engelberg and William Broad, *Germs* (2001) pp. 15-33. The cult sought to influence an election by disabling their opponents. "By the end of the outbreak, almost a thousand people had reported symptoms to their doctors or the hospital; 751 were confirmed to have salmonella …" (Ibid. pp. 19-20). See also, W. Seth Carus, "The Rajneeshees" in Jonathan B. Tucker, *Toxic Terror: Assessing Terrorist Use of Chemical and Biological Weapons* (2000).

48 Kenneth Luongo and William Hoehn III, "Reform and Expansion of Cooperative Threat Reduction," *Arms Control Today*, vol. 33, no. 5 (June 2003) http://www.armscontrol.org/act/2003_06/luongohoehn_june03.asp. See also,

"UZBEKISTAN: US to increase aid to reduce biological weapons" IRIN News (United Nations Office for the Coordination of Humanitarian Affairs), August 28, 2004 http://www.irinnews.org/report.asp?ReportID=42654&SelectRegion= Central_Asia&SelectCountry=UZBEKISTAN.

49 Weber, op. cit.

50 See "BioIndustry Initiative of the U.S. Department of State: Annual Report, 2003" and www.bii.org.

51 Second-order problems (the diversion of funds, etc.) afflict these programs. Over time a new set of issues will arise: How do we employ or support older workers whose skills are outmoded? Do we want to provide support for the proliferation of new skills amongst Weaponeers?

52 I derive this judgment from conversations with those centrally involved in the effort and from one commendably precise, though limited, analysis. At the end of 2003, Deborah Yarsike Ball and Theodore P. Gerber employed a Russian survey firm to query 603 Russian physicists, chemists and biologists about their willingness to entertain job offers from a number of countries, including North Korea, Syria, Iran and Iraq. "Will Russian WMD Scientists Go Rogue? Measuring Russian Scientists' Willingness to Work in High-Threat Countries and the Impact of ISTC" (Unpublished Lawrence Livermore National Laboratory study for the State Department Science Centers Program, January 2004). They found that *"20 percent of our sample would consider taking a job in at least one high-threat country."* (p. 5. Italics in the original.) They recorded substantial differences between the general sample and those who were "principal investigators" on Nunn-Warner grants – only seven percent of those investigators described themselves as open to employment elsewhere. (These results remained significant when variables of age, income, and status were controlled for.) On the other hand, they observed no significant differences between those who participated at a lesser level in grant programs and those who did not participate at all: "ISTC participants who are not project managers are only slightly less likely than those who never applied at all to ISTC (19 percent vs. 23 percent) to demur from the chance to work in a high-threat country" (p. 6). The Russian Academy of Sciences reports that 2,900 Russian scientists emigrated in 2002, of whom a third were biologists. This accounted for five percent of the staff of the 300 Institutes studied. Three quarters of the biologists are reported to have relocated to the United States and Europe. The destinations of others are not reported. (Russian Academy of Sciences, Institute of Economic Forecasting, Center for Demography and Human Ecology, http://www.informnauka.ru/eng/2004/2004-07-19-041_40_e.htm).

53 In these societies we may also hope that hostile states will, from their own self-interest, limit the proliferation from their own scientists to other states. The nuclear proliferation that stemmed from A.Q. Khan is worth studying as a case in point: How well did we track his activities while they occurred? To what extent does his behavior indicate the limits of state control over its own scientists?

54 The number is, not surprisingly, difficult to calculate and subject to debate. To assess order of magnitude, however, it may be helpful to consider a society to which we have complete access: our own. How many Americans might be able, with trial and error, to aerosolize an effective biological weapon? As a rough indicator I note that the most recent data from the Bureau of Labor Statistics reports 75,000 biological scientists (http://www.bls.gov/oco/ocos115.htm), 48,000 biological technicians (Ibid.), 20,000 agricultural and food science technicians(ibid.), 58,000 "medical scientists" (http://www.bls.gov/oco/ocos008.htm), 583,000 medical doctors not included in the first categories (http://www.bls.gov/oco/ocos074.htm), and 58,000 veterinarians (http://www.bls.gov/oco/ocos076.htm). In addition, the National Science Foundation calculates that there are 61,132 graduate students in biological sciences (National Science Foundation, Division of Science Resources Statistics, "Graduate Enrollment in Science and Engineering Fields Reaches New Peak; First-Time Enrollment of Foreign Students Declines," NSF 04-326 (June 2004), http://www.nsf.gov/sbe/srs/infbrief/nsf04326/start.htm). Of course, these numbers are only suggestive and skills within this group are widely variable. Their total of 903,132, however, points to the magnitude of the problem. (Another indicator is that between 1966 and 2001 American institutions are calculated to have awarded 2 million B.S. degrees, some 270,000 M.A. degrees, and some 50,000 Ph.D.s in biology. http://www.nsf.gov/sbe/srs/nsf04311/pdf/nsf04311.pdf, Table 47.) World-wide data is yet less precise, but obviously amplifies the relevant numbers. As examples, I note: In the late 1990s there were some 78,000 doctors in Pakistan. (I calculate this by multiplying WHO figures for doctors per 100,000 population in 1997 by the reported population at the time. World Health Organization, http://www3.who.int/whosis/health_personnel/health_personnel.cfm; U.S Bureau of the Census, International Database.) In the same period, there were some two million doctors in China (Ibid., 1998 figures). In 1999, some 2.6 million students are estimated to have received B.S. degrees in science and technology. Almost half of these were earned at institutions outside the United States and Europe. http://www.nsf.gov/sbe/srs/seind02/c2/c2s4.htm World-wide, it could be argued that the number of The Broadly Skilled capable of developing biological weapons is in the many millions. It will suffice for purposes of this paper to suggest that it is over a million and thus that the

group as a whole is not realistically susceptible to the one-on-one engagement and surveillance that can be (heroically) pursued with regard to the Weaponeers.

55 The context of the effort certainly matters. Larger and better financed efforts are more likely to produce large quantities of agent and the agent is likely to be more efficient and more effective.

56 The perpetrator of the 2001 anthrax letter attacks may be just such a biological Unabomber.

57 International scientific associations may be particularly helpful in this regard. John Steinbruner and Elisa Harris comment that "Few U.S. officials appear to recognize the global scope of the microbiological research community, and thus the global nature of the threat." ("Controlling Dangerous Pathogens," *Issues in Science and Technology* (Spring 2003) http://www.issues.org/issues/19.3/steinbruner.htm.) Steinbruner and Harris suggest a system of peer committees to review "high-consequence biological research."

58 Mathew Meselson, "Averting the Hostile Exploitation of Biotechnology," *CBW Conventions Bulletin* 48 (June, 2000) p. 16; Malcolm Dando and Graham S. Pearson, "The Fourth Review Conference of the Biological and Weapons Convention: Issues, Outcomes and Unfinished Business" *Politics and the Life Sciences* 16, no. 1 (March 1997), pp. 105-126.

59 See generally, Steinbruner, John and Elisa D. Harris, op.cit.

60 Jeronimo Cello, Aniko V. Paul, and Eckard Wimmer, "Chemical Synthesis of Poliovirus cDNA: Generation of Infectious Virus in the Absence of Natural Template," *Science* 297 (2002), pp. 1016-1018; Ronald J. Jackson et al., "Expression of Mouse Interleukin-4 by a Recombinant Ectromelia Virus Suppresses Cytolytic Lymphocyte Responses and Overcomes Genetic Resistance to Mousepox," *Journal of Virology* 75, no. 3 (February 2001), pp. 1205-1210. The rapid creation of a synthetic virus by Craig Ventner's Celera Corporation points to the same problem. "Generating a synthetic genome by whole genome assembly: phiX174 bacteriophage from synthetic oligonucleotides" *Proceedings of the National Academy of Sciences USA* 100, no. 26 (Dec 23, 2003) pp.15440-5. See generally, Steven Block, "A Not-So-Cheap Stunt" *Science* (2003) pp. 297, 769 and Phillip Ball, "What is Life? Can We Make It?" *Prospect*, August 2004. Noting these and other developments, an unclassified CIA report states: "A panel of life science experts convened for the Strategic Analysis Group by the National Academy of Sciences concluded that advances in biotechnology, coupled with the difficulty in detecting nefarious biological activity, have the potential to create a much more dangerous biological warfare threat." Central Intelligence Agency, "The Darker Bioweapons Future," November 2003, http://www.fas.org/irp/cia/product/bw1103.pdf.

61 A recent report from the National Academy of Sciences argues that our government should rely on a combination of expanding existing regulations and self-regulation by the scientific community, rather than enacting intrusive new policies. Its key recommendations include: the government should not regulate scientific publishing but should rely on scientists and editorial boards to police themselves; create an International Forum on Biosecurity to ensure that regulation applies not just to U.S. scientists but reaches around the world; and require approval for seven types of potentially dangerous experiments – such as creating more virulent or vaccine-proof diseases – from the Institutional Biosafety Committees that already supervise recombinant DNA research at institutions across the United States. Committee on Research Standards and Practices to Prevent the Destructive Application of Biotechnology, National Research Council of the National Academies, *Biotechnology Research in an Age of Terrorism* (Washington, D.C.: National Academies Press, 2004). (This is frequently referred to as "The Fink Report" after its chair.) In response to this report, the National Institutes of Health recently established a National Science Advisory Board for Biosecurity to oversee federally funded life sciences research.

62 Some of these constraints also play a useful role in reducing the risks of accident.

63 Regarding the spotty global efforts, see Tucker op. cit. pp 28-34.

64 They may also inhibit the very research that is required for effective biological defense.

65 I have urged, Danzig, op. cit., that it is important for our intelligence agencies to form a Case X committee that will engage academics and pharmaceutical and biotechnology experts to monitor scientific developments that may lead to new pathogens. A committee of this type would help identify indicators and warnings and provide advice on the allocation of our operational and analytic resources.

66 Investment in this regard will yield the additional value of substantial collateral gains in countering natural illnesses.