Survey of Bioscience Research Practices in Asia: Implications for Biosafety and Biosecurity

Jennifer Gaudioso[1] and Tamara Zemlo[2]

[1]Sandia National Laboratories, Albuquerque, New Mexico and [2]BioInformatics, LLC, Arlington, Virginia

Abstract

Over 300 Asian life scientists were surveyed to provide insight into their work with infectious agents. This survey was designed to inform our understanding of the state of biosciences, laboratory biosecurity, and biosafety in Asia. The survey results can help to identify and address gaps in the development and implementation of policies and practices related to laboratory biosafety and biosecurity. In September and October of 2005, BioInformatics, LLC (Arlington, Virginia, USA) conducted a 30-question online survey. The questionnaire was fielded to registered members of The Science Advisory Board. Sponsored by BioInformatics, LLC, The Science Advisory Board is an online community of more than 28,000 scientists, physicians and healthcare professionals from around the world. The Science Advisory Board members who participated in this study were drawn from the Board's Research Panel and supplemented by additional qualified life scientists. For analysis, countries were divided into three tiers based upon their level of biotechnology sophistication: advanced (China, Hong Kong, India, Japan, South Korea, and Singapore), emerging (Malaysia, Pakistan, Taiwan, and Thailand), and developing (Bangladesh, Cambodia, Indonesia, Philippines, Sri Lanka, and Vietnam).

The respondents have a variety of research objectives and study over 60 different pathogens and toxins. Many of the respondents indicated that their work was hampered by a lack of adequate resources and difficulty in accessing critical resources. The survey results also demonstrate that there appears to be better awareness of laboratory biosafety issues as compared to laboratory biosecurity. Most laboratories employ simple biosecurity measures. Perhaps not surprisingly, many of these researchers work with pathogens and toxins under less stringent laboratory biosafety and biosecurity conditions than is typical for laboratories in the West. Fortunately, the study indicates that these respondents might be receptive to credible, unbiased information on biosafety and biosecurity policies and procedures. One straightforward way to do so is to take advantage of respondents' desire to stay connected with their scientific colleagues via collaborations. Only eight percent of respondents' laboratories do not collaborate.

Introduction

Many countries in the world have chosen to seek economic growth through large national investments in biotechnology. For example, Singapore has spent $300 million USD to build Biopolis, a hub for biomedical research (Tong, 2004). South Korea is keeping pace with its neighbor—in 2000, only one Korean biotechnology firm was listed on the Korean Stock Exchange, but 23 were listed by 2003 (Wong et al., 2004). Malaysia has formed the Malaysia-M.I.T. Biotechnology Partnership Program, which developed the strategic plan for BioValley Malaysia, a cluster of three national biotechnology institutes (www.nbbnet.gov.my/plan.htm). However, what is not clear is whether this investment has been coupled with sufficient planning toward securing and maintaining adequate biosafety and biosecurity precautions.

Since Asian bioscience laboratories are critical players in the global battle against emerging and re-emerging infectious diseases, such as Avian Influenza, Severe Acute Respiratory Syndrome virus (SARS), Nipah, Chikungunya, epidemic meningitis, hantavirus, Human Immunodeficiency Virus (HIV), and Rift Valley Fever, among many others, these labs are vulnerable to unintentional *and* intentional breaches of containment (Fauci, 2006). Bioterrorism can be considered a "deliberately re-emerging infectious disease" (Morens et al., 2004). There is a concurrent increase in the number of Asian bioscience laboratories that handles infectious biological agents, due in part to the expanding need for diagnostics to support disease surveillance, research into basic pathogenesis, and drug development.

While these laboratories are critical in the fight against infectious diseases, they also present serious implications for international health and security if staff personnel do not handle the biological agents safely and securely. Laboratory-acquired infections of contagious diseases have demonstrated the potential to spread beyond the laboratory into the community. In fact, after smallpox was eradicated, incidences of smallpox spreading from the laboratory to the community (England had three secondary cases of smallpox in the community as a result of laboratory-acquired infections in 1973 and 1978) were one of the motivating factors for consolidating Variola virus at only two repositories (Fenner et al., 1988). More recently, multiple incidents of laboratory-acquired SARS (Singapore in September 2003, Taiwan in December 2003, and Beijing in March 2004) occurred after the virus stopped circulating naturally. The Beijing laboratory-acquired infection (LAI) spread into the community, resulting in nine cases of SARS (three generations) (WHO, 2004a). LAIs occur throughout the world. Recent examples include Ebola in Russia (2004), vaccinia in Brazil (2002), and tularemia in Boston (2004). However, at least in part because the SARS LAIs occurred after the virus was no longer circulating in humans, LAIs have helped to generate a greater awareness in Asia of the need to ensure that dangerous pathogens are handled responsibly.

The illicit acquisition of dangerous pathogens from legitimate facilities is more difficult to identify. Nonetheless, there are multiple examples (Salerno et al., 2004):

- Dr. Suzuki stole *Salmonella typhi* cultures from the Japanese National Institute of Health (1964).
- The Weathermen group attempted to convince an employee at Ft. Detrick to obtain pathogens for them (1970).
- In 1995, a laboratory technician removed *Shigella dysenteriae* Type 2 from a hospital's collection and infected co-workers.
- The Rajneeshee cult acquired *Salmonella typhimurium* from a medical supply company (1984).
- And, in the most well-known case, the *Bacillus anthracis* used in the anthrax letters of 2001 is believed to have originated from a U.S. biodefense laboratory.

Additionally, given breakthroughs in the efficiency of nucleic acid synthesis, coupled with easy access to pathogenic sequences, the threat of bioterrorism is no longer limited to naturally occurring organisms. The acquisition of all of the appropriate gene sequences through companies providing custom oligonucleotides has become an increasing concern given the anonymity of ordering via the Internet.

The objective of laboratory biosafety is to reduce the likelihood of an accidental exposure to staff, or the environment, while laboratory biosecurity aims to minimize the risk that materials at the laboratory could be used maliciously. Both disciplines ultimately strive to keep dangerous pathogens safely contained within the laboratory environment. This study was designed to examine the policies and standards that Asian scientists employ to advance biosafety and biosecurity in their laboratories. Specifically, a need exists to better understand the practices, equipment, and facilities used by these researchers, and to examine existing regulations associated with the infectious pathogens they study. By analyzing this information, gaps in the implementation of policies related to biosafety and biosecurity can be identified and addressed.

Moreover, this study also spotlights the intersection of the risks that Asian scientists feel in researching specific pathogens, and links these perceptions to the realities of their biosafety and biosecurity policies and procedures. It provides readers with a more complete understanding of current practices employed in laboratories located in Asian countries that study infectious agents and pathogens.

Survey Methodology

This paper is based on responses to a 30-question online survey conducted by BioInformatics, LLC (Arlington, Virginia, USA) for Sandia National Laboratories. A total of 300 Asia-based life scientists who study infectious agents and/or toxins in their laboratory participated in this survey between September 20 and October 22, 2005. How were the questions selected? The survey questions were primarily designed to be exploratory in nature and assess the following study objectives:

- Types of pathogens and/or toxins used in research
- Research objectives as they pertain to these pathogens and/or toxins
- Laboratory capacity, including tools and techniques available, personnel, and physical structure
- Status quo for biosafety and biosecurity policies and procedures
- Perceptions of risk
- Standards and accountability measures

The structure of the questionnaire was based upon a 2004 report produced by BioInformatics, LLC designed to benchmark the state of biodefense research in the U.S.

The questionnaire was fielded to registered members of The Science Advisory Board. Sponsored by BioInformatics, LLC, The Science Advisory Board is an online community of more than 30,000 scientists, physicians and healthcare professionals from around the world. The Science Advisory Board is divided into two panels (Research and Clinical) and "convenes" regularly via the World Wide Web (www.scienceboard.net) to voice opinions on a wide variety of issues relating to biomedical research and clinical technologies. These experts—representing all aspects of the life sciences and medicine—have agreed to make themselves available to participate in BioInformatics' online research activities. The Science Advisory Board members who participated in this study were drawn from the Board's Research Panel and supplemented by additional qualified life scientists. Members of The Science Advisory Board represent a segment of the scientific community who has demonstrated a willingness to participate in market research activities. These factors may inject a certain level of bias into the findings presented in this report, and any subsequent analysis should be viewed in this light.

Each of the qualified respondents received a personalized e-mail message containing a unique Uniform Resource Locator (URL) directing them to the online questionnaire. The e-mail message described the objectives of the study, the incentive for participating, and a privacy guarantee. The online questionnaire was designed to take a maximum of 15 minutes to complete. Results were tallied automatically through a proprietary software application developed by BioInformatics and analyzed using the Statistical Package for the Social Sciences (SPSS). The online questionnaire consisted of 29 closed, or partially close-ended questions, and one open-ended question designed to encourage participation and to meet the objectives of the study. Question 21 was the open-ended question and was characterized by a somewhat lower response rate. This may be attributable to a common tendency of respondents to skip relatively challenging, or time consuming questions, or hesitancy to name a specific company when they are unsure of who is sponsoring the survey. The lower response rate to Question 21, and occasionally to others, explains why the total number of responses to a question is sometimes less than the total number of respondents to the survey. If an answer choice was not selected by any of the respondents, the answer choice may have been omitted from the analysis, rather than listing answer choices with a zero value.

The complete questionnaire and a presentation of the survey data can be found on the Sandia National Laboratories' web site at www.biosecurity.sandia.gov. The questionnaire was divided into seven sections. The first section had three questions aimed at understanding the research objectives of the respondent's institution, including which infectious organisms they studied (if "none" was selected, the respondent did not continue the survey), the focus of their work (e.g., vector control strategies, pathogenesis) and the stage of their research (e.g., basic, drug development). The second section was a single question with a checklist of tools and techniques that their laboratory used to study infectious agents. The section on biosafety and biosecurity was the largest topic of the survey with 10 questions on risk assessment, program management, biosafety levels, biosafety practices, and biosecurity practices. The next survey topic focused on risk perceptions in an attempt to gauge how concerned respondents were about laboratory biosafety and biosecurity. The three questions on "Communication and Networking" were selected to provide some insight into how respondents keep abreast of developments in their fields, and the extent of their collaborations. The "About Your Laboratory" section asked basic questions about the size and type of the respondent's institution. This section also had a few questions on the difficulties these laboratories face in meeting their mission. The last set of questions "About You" asked respondents for basic information about themselves such as their position and level of education.

To facilitate a comparative analysis, respondents were divided into three categories based upon the state of their country's research infrastructure, as defined in Table 1. Country tiers were established based upon the estimated biotechnology sophistication level of the respective countries where the profiled labs are located. These determinations were made based upon information provided by a variety of secondary sources, including the CIA World Fact Book, the USDA Foreign Agricultural Service GAIN Report, country-specific biotech publications, supporting documents of the United Nations Environment Program, and country-specific government publications.

Types of Agents Studied

Unsurprisingly, respondents representing such diverse fields as virology, microbiology, toxicology, and pathology perform research on a wide variety of organisms. Despite this assortment, some distinct trends emerge. More respondents study bacteria than viruses or toxins. *Salmonella typhi* was the most frequently investigated infectious agent, followed by *Escherichia coli* O157:H7 and *Vibrio cholerae*. Overall, food-borne pathogens are the most commonly studied, but there was also an emphasis on diseases exotic to the U.S., such as dengue fever virus, Japanese encephalitis virus, and the highly pathogenic avian influenza virus. Furthermore, many laboratories work with biological agents that the U.S. considers to be of potential bioterrorism concern. Table 2 highlights potential bioterrorism agents (Rotz et al., 2002) as determined by the Centers for Disease Control and Prevention (CDC) that are studied by respondents. Variola major, a Category A agent, is not included in the table below; only two bioscience facilities (CDC in Atlanta, USA, and Vector in Russia) are authorized to have this agent. *Francisella tularensis* is the other Category A agent missing from Table 2. Only one respondent studied this agent.

The CDC Category A, B, C lists as identifiers of bioterrorism agents are problematic, in part because these lists do not consider potential agricultural threat agents. These lists are used for the table above, because those categories are more familiar to non-U.S. scientists than

Table 1

Country tiers based on biotechnology sophistication.

Advanced (Respondents=162)	Emerging (Respondents=91)	Developing (Respondents=47)
China	Pakistan	Indonesia
Hong Kong	Thailand	Cambodia
Japan	Taiwan	Vietnam
Korea	Malaysia	Bangladesh
Singapore		Philippines
India		Sri Lanka

Table 2

Category A, B, C agents studied by respondents.

CDC Category	Agent	% of respondents studying the agent
A	*Bacillus anthracis*	14%
A	*Yersinia pestis*	9%
A	*Clostridium botulinum* / botulinum toxins	13% / 26%
A	Filoviruses and Arenaviruses	1% for Filoviruses; no reported work with Arenaviruses
B	*Coxiella burnetii*	3%
B	*Brucella abortus*, *melitensis*, or *suis*	8%
B	*Burkholderia mallei*	7%
B	*Burkholderia pseudomallei*	14%
B	Eastern Equine Encephalitis virus	3%
B	*Rickettsia prowazeki*	3%
B	Toxins	21%
B	*Chlamydia psittaci*	3%
B	Food Safety threat: Salmonella typhi	57%
B	Food Safety threat: *Escherichia coli* O157:H7	52%
B	Food Safety threat: *Shigella dysenteriae*	33%
B	Water Safety threat: *Vibrio cholerae*	42%
C	Emerging threat: Hanta virus	10%
C	Emerging threat: Nipah and Hendra complex viruses	8%

the more expansive CDC and USDA select agent lists. Biological agents studied by respondents that are of likely concern to the U.S. due to their potential for agricultural bioterrorism include (all on the USDA select agent list): avian influenza (highly pathogenic) (23%), foot and mouth disease virus (13%), Newcastle Disease virus (10%), classical swine fever virus (7%) and Rinderpest virus (1%). While SARS is not on any of the Category A, B, C lists, or the select agent lists, it is studied by 23% of the respondents, most commonly in laboratories in developing countries.

Laboratories throughout the region have many common research targets. For example, HIV and dengue fever virus are the most universally studied viruses. Yet, there are also some key distinctions in research focus; Table 3 highlights these differences for the top infectious agents studied by tier. Emerging infectious agents, such as avian influenza and SARS, are more often studied by laboratories in developing countries. In fact, the most commonly studied infectious agents in developing countries are dengue fever virus and the highly pathogenic avian influenza virus; neither of these was among the most common for emerging or advanced countries. The top two infectious agents for these tiers were *Salmonella typhi* and then *Escherichia coli* O157:H7.

The pathogens and toxins studied generally reflect the top public and agricultural health concerns of the country. In the study population, a higher percentage of Indonesian researchers than any other country's researchers are investigating avian influenza virus. Vietnam and then Malaysia have the next highest fractions of researchers in the survey who study avian influenza virus. Taiwan and Singapore have more study respondents working on SARS than any other country included in the survey. Malaysia and Taiwan had the most researchers studying *Burkholderia mallei* and *B. pseudomallei*. Human immunodeficiency virus was the most popular research target for respondents from China, Japan, and South Korea. *Salmonella typhi* was the most common infectious agent examined in the laboratories of respondents from India, Malaysia, Pakistan, and the Philippines. Overall, in this study, India appeared to be the most active in researching a diverse set of pathogens and toxins.

Table 3

Top infectious agents studied by country tier. The percentages of respondents that study the two most common infectious agents in each tier are bolded.

Infectious Agents	Advanced Tier	Emerging Tier	Developing Tier	Total Respondents
Salmonella typhi	**31%**	**22%**	21%	**27%**
Escherichia coli O157:H7	**28%**	**22%**	19%	**25%**
HIV	20%	13%	17%	17%
Dengue fever virus	10%	15%	**34%**	16%
Shigella dysenteriae	17%	13%	17%	16%
Japanese encephalitis virus	9%	12%	21%	12%
Avian influenza virus (highly pathogenic)	4%	9%	**23%**	9%
Staphylococcus aureus toxins	10%	7%	4%	8%

Research Focus and Supporting Technologies

Slightly more than one-third of respondents conduct basic research. The majority of the remaining researchers are evenly divided into the following areas: drug discovery and development, clinical work, and disease surveillance. Respondents identified diagnostics and epidemiology as the major foci of their research efforts. However, the focus changed with the various stages of research. For instance, basic researchers were more often associated with pathogenesis studies, while clinicians focused more on diagnostics. Given that many respondents investigate bacteria-caused infections, it would be expected that more drug discovery and development researchers' work would be conducted on antibiotics rather than on antivirals. As epidemiology is most closely linked to disease surveillance, many of the respondents' laboratories in the developing countries likely serve a critical public health need. In fact, they are about one-and-a-half times more likely to be repurposed by their governments to assist during an epidemic than their counterparts in emerging and advanced countries.

Laboratories employ a variety of modern biotechnology tools (Figure 1). Biotechnology spreads rapidly, but the distribution of new technologies is not ubiquitous. Study respondents most often use such basic techniques such as classical Polymerase Chain Reaction (PCR) (60%), electrophoresis (57%), and enzyme-linked immunosorbent assays (ELISAs) (56%). More sophisticated technologies—typically used for gene expression analysis—like microarrays and RNAi are not as popular (both used by 11% of respondents). However, the 11% figure for RNAi demonstrates a rather rapid spread of the new technology; small RNAs were named a breakthrough of the year by *Science Magazine* as recently as December 2002.

Biosafety and Biosecurity Practices

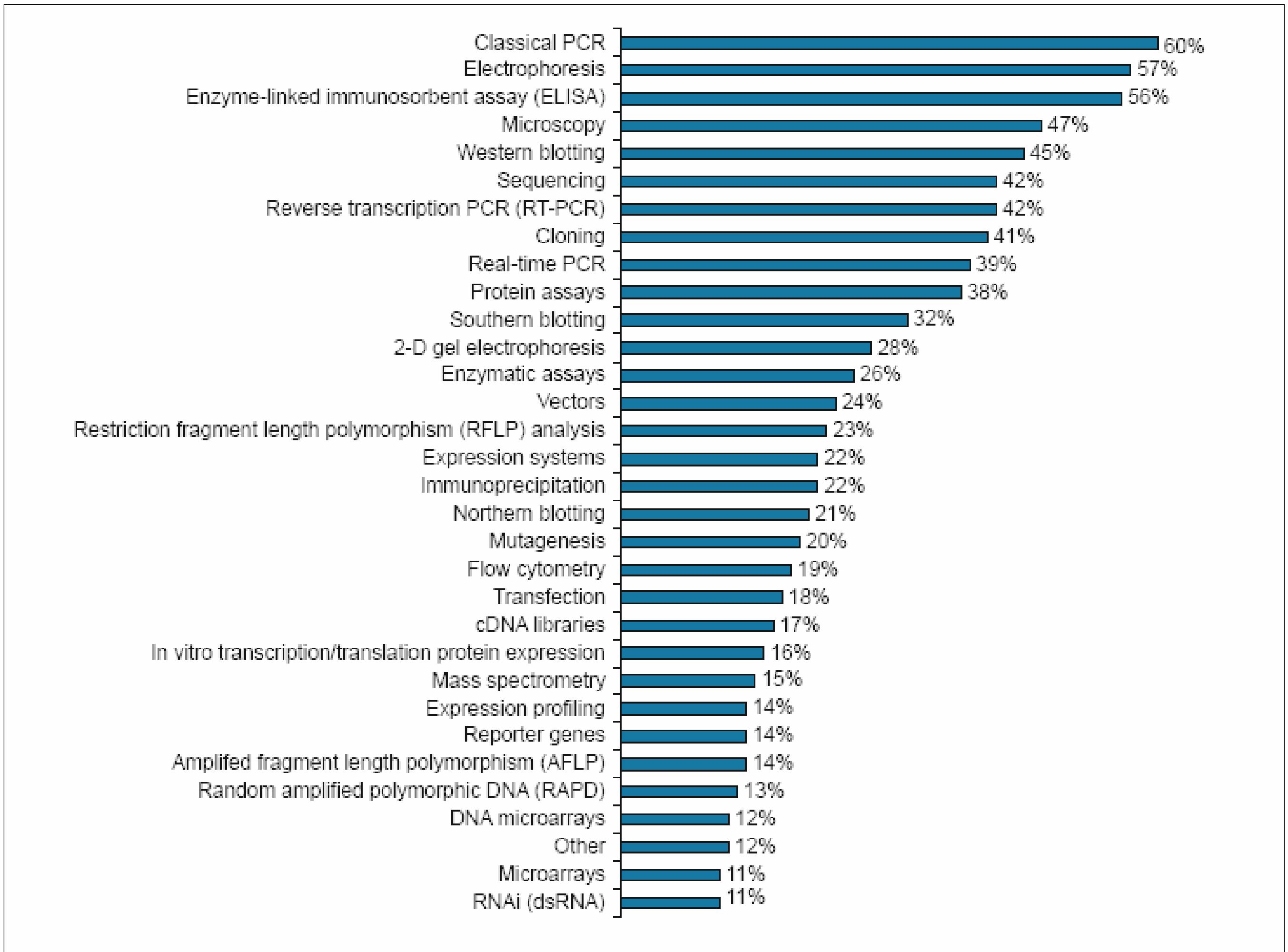
The third edition of the World Health Organization's (WHO) Laboratory Biosafety Manual (WHO, 2004b) defines Biosafety Level 1 and 2 (BSL-1 and BSL-2) as basic bioscience laboratories, while BSL-3 and BSL-4 are considered containment laboratories (BSL-4 is "maximum containment"). As expected, respondents most commonly work in basic bioscience laboratories: 58% of respondents work in BSL-2 and 22% in BSL-1 laboratories. Containment laboratories are far less common: 18% of the respondents have BSL-3 laboratories and 2% have BSL-4 laboratories. Yet, 21% of the respondents did not know the biosafety level of their laboratory. This is somewhat alarming, especially since 72% of the respondents have PhDs.

Biosafety in this region often fails to meet international standards. Five of the top nine infectious agents identified by respondents should be studied under BSL-3 conditions, according to the WHO and CDC. However, nearly two-thirds of respondents investigating Japanese encephalitis, avian influenza, and SARS perform their research in BSL-2 laboratories. Furthermore, 54% of those studying HIV, and 62% of those working on *Escherichia coli* 0157:H7 use a BSL-2 setting. Biosafety risk assessments can alter the biosafety level recommended for containment of particular pathogens. The results of a risk assessment conducted in countries where the disease is endemic may lead to a different (lower) perception of risk than in countries where the pathogen under study does not occur naturally. Nonetheless, facilities can implement key biosafety and biosecurity principles even with limited financial and personnel resources (Fisher-Hoch & McCormick, 2004).

If respondents do not have a particular piece of safety equipment necessary to perform an experiment, just un-

Figure 1

Research techniques used by respondents.



der half of them will conduct the experiment anyway by either modifying existing equipment, or creating new pieces of equipment. All of the survey respondents' work with infectious materials, yet only 83% use personal protective equipment (PPE) such as gloves, face shields and gowns. Two-thirds of respondents decontaminate their waste before disposal, yet only slightly more than half of the respondents have an autoclave on site for this purpose. The survey did not address other means of decontamination; it is unclear if the other respondents rely on chemicals, incineration, or other mechanisms for decontamination. Approximately 62% of the respondents indicated that they have a biological safety cabinet (BSC), although the survey did not ask for details about the type of BSC being used.

Laboratory biosecurity systems are designed to reduce the likelihood of theft of dangerous pathogens or toxins. Properly implemented laboratory biosecurity is not just physical security; it requires a multi-faceted approach that also includes personnel security, material control and accountability, transport security, and information security. Simple biosecurity measures are routinely employed by the survey population. At least half of the respondents' laboratories always have a guard posted at the buildings entrance, lighted buildings at night, and locked cabinets. Other security measures used around the clock by at least one-third, or more of the respondents are access control devices, locked building doors and refrigerators, and security patrols. Laboratories located in developing countries, in contrast to those located in advanced and emerging countries, tended to have personnel dependent security measures such as guards and patrols. More sophisticated physical protection measures, such as intrusion sensors and alarms, as well as video monitors are not nearly as commonplace.

Slightly more than half of the respondents' laboratories restrict access to laboratory areas at all times. At least two-fifths of respondents' laboratories monitor access to the restricted areas by using employee lists, photo identification badges, and records of keycard assignments. Building escorts are the most variable personnel security measure and are often used in laboratories of advanced countries. Nearly three-quarters of the respondents indicated that their institution screens potential employees at least some of the time; only one-third do so all of the time. Background screening seemed to occur more frequently in laboratories located in developing, rather than advanced and emerging countries.

Password protection of computers and files is the most likely information security measure to be employed. Maintaining a laboratory's computer network and destroying sensitive documentation are measures slightly more than one-half of respondents' laboratories always perform.

Awareness of infectious agents or toxins by either the laboratory head or direct supervisor is one of the most common ways the majority of respondents' laboratories implement material control measures. Slightly more than half (54%) have a current inventory record of infectious agents and/or toxins.

The Chinese Ministry of Health investigation (Western Pacific Region, 2004) of the laboratory-acquired SARS cases in 2004 concluded that they occurred "due to poor safety management of laboratories, flawed implementation of regulations, and violation of biosafety rules by laboratory workers." Poor program management was the root cause of the infections in all of these situations. Poor supervision, lack of biosafety policies and standard operating procedures, insufficient training, and lack of accountability were common to all of the affected laboratories. Inadequate program management in laboratories throughout Asia was evident in responses from those working in containment laboratories (BSL-3 and BSL-4). Approximately 25% indicated that they did not have a biosafety manual, and 25-33% lack procedures for training their staff on biosafety protocols. Not surprisingly, responses indicated that program management of biosafety for BSL-1 and BSL-2 laboratories, and biosecurity of all, are even more deficient. Poor program management is a real concern given the rapid proliferation of containment laboratories globally. It is impossible to know the number of BSL-3 laboratories worldwide, but it is clear that the number is rapidly increasing (Gaudioso, 2006). For example, in 2003, Singapore had just three BSL-3 laboratories, but aims to establish 15 BSL-3 laboratories, reportedly doubling the number of BS-L3 laboratories in 2005 alone. Bioscience facilities everywhere are rapidly increasing in number; these facilities must work to strengthen institutional support and oversight of laboratory biosafety and biosecurity. Respondents were asked about their sources of laboratory biosafety guidance, or regulations. In all tiers, the starting place was information and regulations provided by their own country's government. The WHO and the U.S. Centers for Disease Control and Prevention (CDC) were the other primary resources. As the degree of containment increased, respondents were more likely to rely on CDC and WHO guidance.

Key Challenges and Needs of Asian Researchers

Expense, lack of equipment, and delayed shipments are among the top problems that researchers' experience. However, most difficulties are country and tier-specific. Respondents from advanced countries most often complain about the expense of conducting their research. The cost of research is also a concern for respondents from emerging and developed countries, but typically other problems overshadow costs. For example, respondents in emerging countries also cite limited access to necessary equipment, a lack of qualified staff, and difficulty in shipping infectious agents as frustrations they experience. Respondents from developing countries also worry about the lack of appropriate instrumentation and delayed shipments of laboratory supplies.

In addition to logistical difficulties that must be surmounted to conduct their research, respondents face technical challenges. Greater than one-third of respondents require outside assistance with animal models. Respondents whose laboratories are located in either advanced, or emerging countries also need support in preparing, or obtaining antibodies for capture and differentiation. In contrast, respondents whose laboratories are located in developing countries reported most often requiring technical assistance with determining virulence-associated traits, distinguishing characteristics and diagnosis, and cultivating the infectious agents that they study. Limited access to infectious agents or toxins is *not* a significant problem for the vast majority of respondents.

The survey did not specifically address how respondents successfully dealt with these issues. For example, we did not learn how respondents identify qualified personnel, or where they obtain their agents for study. However, many of the respondents have established collaborations. These collaborations may be one mechanism that they use to address some of these challenges. Not surprisingly, the vast majority of laboratories collaborate (only eight percent of the respondents' laboratories have no collaborations). Most of these relationships are either established locally (within one's organization), or within one's country. Many laboratories collaborate with international colleagues. Roughly eight percent more respondents collaborate with researchers in the U.S. than they do with researchers located elsewhere in Asia. This increased reliance on American scientists is more evident in laboratories located in developing rather than advanced or emerging countries. Thirty-two percent of laboratories in advanced countries have collaborations with laboratories located in the U.S., and 26% of emerging laboratory respondents have U.S. collaborators. In contrast, 57% of developing laboratories have U.S. collaborations.

Conclusions

This study indicates that scientists are generally aware of the safety and security risks associated with their work.

Respondents are concerned about their pathogens being the source of accidental or deliberate incidents:

- 73% of respondents are concerned about accidentally infecting people, animals, or the environment;
- 70% of respondents are concerned about getting a laboratory-acquired infection;
- 65% of respondents are concerned that their pathogens could be used to cause harm;
- only 15% of respondents believe it is likely, or very likely that pathogens from their laboratory will be stolen by employees or non-employees.

This high level of concern by respondents indicates that there is an opportunity to translate this awareness by into action. Mechanisms to enhance laboratory biosafety and biosecurity include collaborations, training, conferences, and other forums to demonstrate that these practices are integral elements of good laboratory practices, and the development and dissemination of appropriate international standards. Conferences provide venues for meeting colleagues that have similar interests and concerns—recently, there have been several well-attended conferences in Asia focused on laboratory biosafety and biosecurity. (Asia-Pacific Biosafety Association, Annual Meeting, March 2006, 2007, www.a-pba.org; Asia Conference on Laboratory Biosafety and Biosecurity, April 2007, www.AsiaBiosafetyandSecurity.org; Biosafety and Biosecurity Asia 2007, May 2007, www.biosecasia.com). As the BSL increases from one to two and from two to three, more respondents' laboratories turn to sources of guidance from outside their own country. The two principal resources are WHO's *Laboratory Biosafety Manual* (LBM—the third edition is available in English, French, Portuguese, Spanish, Chinese, Russian, and Italian) and the CDC's *Biosafety in Microbiology and Biomedical Laboratories.* Thus, it is important for both of these manuals to address both laboratory biosafety and laboratory biosecurity. For the first time, the third edition of the BMBL (published in late 2004) included a chapter on the "Principles of Laboratory Biosecurity."

The WHO has an international network of collaborating centers for infectious disease diagnostics and research. As a result, the WHO has a unique opportunity to leverage this network to promote responsible laboratory practices globally. The WHO should require adherence to the WHO biosafety manual as one of the terms of reference for such collaborations. If that standard is too onerous for some collaborating centers to meet immediately, they should be required to submit a plan for how they will meet that internationally-accepted standard over a reasonable timeframe (within five years).

These collaborations are a unique opportunity to enhance the laboratory biosafety and biosecurity at these laboratories; collaborators should include these concepts as part of the good laboratory practices that form the foundation of technical collaboration. One straightforward way is to take advantage of respondents' desire to stay connected with their scientific colleagues via collaboration. To stay current in the field, most rely on multiple resources including journals, conferences, e-mail, and the Internet—all channels that can be used to provide the most up-to-date information and critical feedback on research practices. Fortunately, the study indicates that these respondents might be receptive to receiving credible, unbiased information on biosafety and biosecurity policies and procedures. Finally, because the expense of conducting research in Asia is of major concern of respondents, any means by which to minimize the additional costs of biosafety and biosecurity practices will help to ensure that these practices are successfully implemented.

Author's Note

This work was created under U.S. Government contract by employees of Sandia National Laboratories as part of their official duties. The U.S. Government retains non-exclusive rights to use the work.

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