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Protecting society: Biological security and dual-use dilemma in the life sciences-status quo and options for the future

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Life science research is a main pillar of health care; major discoveries have considerably improved life expectancy and quality of life. However, research, technologies and materials that can be used for good can also be misused to harm humans, animals or the environment. This dichotomy is described by the term ‘dual-use’, which applies to all scientific research that has the potential for doing both ‘good’ and ‘bad’. Yet, societal support and acceptance for modern science crucially depends on the public having confidence in the protection from the potential ‘bad’, so the question is whether we, the society, are reasonably protected.

The term dual-use was linked initially to the military sector and nuclear physics research at a time when it became obvious that nuclear fission could be used not only to create energy, but also to incinerate millions and destroy cities [1,2]. Control regimes such as the Treaty on the Non-Proliferation of Nuclear Weapons were put in place to reduce the risk of abuse as much as possible, but the risks of potential misuse keep emerging in other fields of science, notably in computer science and the life sciences.

Generally, the misuse of knowledge and research tools in the life sciences can be divided into three basic categories: criminal acts, biological weapons of mass destruction and bioterrorism. The 2001 attacks in the USA that killed five people by using anthrax-laced letters, however, changed how the life sciences and security interact and overlap. The dual-use dilemma has again become the focal point of intense discussion within the life science community and—albeit catalysed by the media—among the general public. This renewed discussion was initiated by two transmissibility studies of H5N1 avian influenza virus [3,4]. These studies show hallmark features of dual-use research (DUR). Although they were aimed at finding ways to prevent a devastating influenza pandemic—in accordance with the WHO research agenda for influenza [5]—they involved the creation of modified, more transmissible viruses. This simple act seemed to enhance the chances of a pandemic, owing to either a lab accident or intentional release by terrorists.

There are systems in place to deal with these risks. The first is ‘biosafety’: the safe handling of biological materials, including training, use of adequate protection and safe transportation of samples to prevent accidental release, contact or infection with a biological agent. The second system is ‘biosecurity’, which involves secure handling, access control for facilities and material, secure data storage and even publication policies. Security measures aim at preventing someone with malicious intent from accessing material or information that could be misused. A third term,

‘biosurety’, tries to cover biosafety and biosecurity. Biosafety always has to be in place, whereas biosecurity measures have to be applied whenever a relevant risk becomes obvious, that is, when dual-use potential becomes apparent. However, almost all life science research can be abused for malicious goals, thus further differentiation is needed to focus on relevant research. This differentiation is achieved by separating general DUR from so-called dual-use research of concern (DURC). DURC has the added characteristics of immediacy and scope, meaning that it can be used directly, without any further work or modification, for malevolent purposes with potentially severe effects on public health.

Stakeholders—including life science researchers themselves, as well as regulators, funding organizations and publishers—might be held partly responsible for a bioterrorist or criminal act. They, therefore, need to be aware of and acknowledge their responsibilities. As a prerequisite, they need to be able to identify research projects with DURC potential and know how to handle these appropriately. The tools to do so are education and guidance on the basis of laws, guidelines and regulations, but also on ethics and personal initiative. One example of self-regulation is the Asilomar Conference on Recombinant DNA that was held in response to concerns about the risks of the, then new, field of molecular biology. Biologists in the field agreed on a research moratorium and discussed appropriate ways to mitigate risks. In the end, this conference laid the ground for the biosafety levels of today [6].

During the H5N1 discussion, some called for a new Asilomar Conference to deal similarly with biosecurity and especially with dual-use concerns. However, the original conference was solely dedicated to biosafety and involved fewer stakeholders—overall, 55 scientists, lawyers, historians and ethicists took part [7]. Today’s issues are more complex: many researchers are already working in areas with DURC potential, and we have to deal with technologies, agents and rapidly increasing amounts of data. Researchers are working for different laboratories and institutions—government and universitylaboratories, biotech companies, the pharmaceutical industry or military laboratories. Therefore, financial, political, ethical or religious concerns might play a role, especially when it comes to subjects such as stem-cell research [8]. Stakeholders in the biosecurity debate have many roles and obligations, with biosecurity often being an appendix to their everyday work.

In the past, the standard training of life scientists did not focus on or even include biosafety, biosecurity or bioethics, with the exception of ethics applied to clinical trials or animal use. Yet, scientists have to evaluate the potential impact of their research on society when they plan a project, as it is being carried out and when they publish the results. This evaluationshould be on the basis of comprehensive risk–benefit analysis which can become complex. It can, therefore, require support from other experts also to avoid any individual bias on the part of the researchers. Other ways to minimize this risk are to use specific guidelines or software tools designed for laboratory biosafety and biosecurity risk management,

such as BioRAM [9].

The way that such a risk–benefit analysis is conducted obviously depends on the institution within which the research is carried out. The interests, resources and capabilities of research institutions vary greatly, depending on size, finances and the 'setting'; is it a public health institute, a university or a military research facility? The setting might also influence risk perception by the institution and the employees. Again, standardized tools could provide guidance to ensure the risk evaluation is comparable between different institutions and fields of research.

Research is generally funded either by governments or private institutions. The act of funding implies a certain responsibility for the intentions and outcomes of the funded project. To address this issue, several major funding agencies have enacted codes of conduct. Examples include the codes of the German Max Planck Society, the German Research Foundation and The Wellcome Trust [10–12]. The US government and the European Union (EU) also published codes of conduct for publicly funded research [13,14]. However, these guidelines or policies are only applicable for those who receive funding from those organizations or governments, and thus leave out independently financed or industry-based research.

Publication is an integral part of research. Journal editors spend their time reviewing manuscripts for their own scientific merits and to guarantee scientific reliability, not for potential biosecurity issues. In many journals, editors are often scientists who volunteer and are usually not paid for their work. As such, there are few training requirements. Is it, therefore, reasonable and realistic to expect editors to competently judge the DURC potential of a submitted manuscript? A survey showed that few editors had experience of biosecurity reviews, and those who had experience had never rejected a publication on those grounds [15]. This is reflected by data from *Nature*-branded journals: in a period of four years, about 74,000 biology submissions were received by different *Nature*-branded journals, 28 of these were flagged for DURC potential and reviewed separately. It was concluded that all of them were DUR but not DURC, thus no papers were rejected because of biosecurity concerns [16].

Whilst most editors agree that they have a responsibility to be vigilant, there is a general lack of guidance on how to identify and judge the DURC potential of a manuscript. It is true that a group of journal editors and authors have described basic requirements and recommendations [17] and that many journals have established policy guidelines, but these are not universal. The initial recommendation to publish the H5N1 studies only in part might be considered as a prominent example of this lack of guidance. Not until then did it become obvious that there were no mechanisms in place for publishing manuscripts in part, whilst at the same time providing full access to the results for some 'chosen' researchers.

Mechanisms to allow or facilitate decision-making can be provided by different 'tools', such as codes, guidelines or laws. The strongest tools are laws, which are enforceable, whereas guidelines are the weakest.

Between these two extremes are several codes—aspirational codes (often referred to as codes of ethics), educational codes (codes of conduct) and enforceable codes (often part of broader guidelines or regulations; [18]). Codes can also be distinguished according to their intention—they can echo existing provisions (codifiers) or refine and explain given rules (clarifiers).

Historically, there are specific international treaties and laws to prevent the proliferation of biological weapons of mass destruction, such as the Biological and Toxin Weapons Convention [19] and the related United Nations Security Council Resolution 1540. The EU also has directives and regulations governing biotechnology. An EU directive has to be transposed into national law by member states that can adapt the law to match their own requirements. By contrast, a regulation directly and equally applies in every EU member state. An example for biosecurity-relevant EU legislation is the guidance on export controls [20].

At the national levels, laws differ widely in terms of specificity and restrictiveness. Only few countries have adopted specific biosecurity laws. Denmark adopted a Biosecurity Law in 2008 that is comprehensive and, among other provisions, requires the monitoring of specified equipment. Many other countries rely on combinations of existing laws from different areas, such as biosafety or export controls. Germany, for example, has several laws that govern aspects of biosecurity but no specific national code or law. These laws include the Act on Genetic Engineering, the War Weapons Control Act, the Foreign Trade Act, the Protection against Infection Act and the Biological Agents Ordinance. Although most dual-use issues are covered this way, these provisions might be insufficient to deal with the possible misuse of new developments, technologies and knowledge.

The USA has implemented a range of domestic laws, regulations and guidelines for biosecurity. The Government Policy for Oversight of Life Sciences Dual Use Research of Concern has come into force in 2012 [14]. This policy is supposed to result in regular stock-taking of research on 15 specific agents and toxins for seven defined categories of experiments. It has already been pointed out that considering only 15 agents, which are already tightly regulated by other means, would not cover enough ground. Looking at previously identified studies with DURC potential, it is obvious that not all of these would fall under this policy [21]. Examples of these studies are the inadvertent creation of a deadly mousepox virus [22] and the *de novo* synthesis of both polio virus [23] and SARS-like bat corona virus [24]. Furthermore, the policy applies only to US government-funded or government-conducted research, whereas privately funded or industry research is not covered.

There are international guidelines, such as the WHO guidelines in the context of the H5N1 studies [25]. Other relevant WHO documents are the Biosafety Manual [26], which also discusses biosecurity for the first time at this level, and the Biorisk Management Guidance, which aims to provide leads for developing national approaches that can merge both traditional

biosafety and new security concerns [27]. Another WHO report offers guidance for addressing the risks of laboratory accidents or potential deliberate misuse [28]. These documents are recommendatory in nature, but are often used as a foundation for more binding national regulations. Other examples include standards provided by the European Committee for Standardization, such as the Laboratory Biorisk Management Standard [29].

Codes of ethics are typically short, general in nature and seek to build consensus on the basis of ethical considerations. The most prominent example is the Hippocratic Oath. The Pugwash Conferences on Science and World Affairs drafted a code of ethics that asks for the active ethical engagement of scientists. The code demands that scientists refuse "to engage in any research, development or use of science that is unethical, in particular, that is intended to facilitate—or when there is a real possibility of its being misused to facilitate—biowarfare or bioterrorism, both of which violate the fundamental moral values of humanity" or "take steps to prevent any research or use of science that is unethical especially that which could facilitate biowarfare or bioterrorism and, in particular, the misuse or potential misuse of one's own discoveries, teachings, knowledge, or scientific advancements for such purposes…" [30]. Therefore, this code demands that scientists take responsibility beyond the laboratory door and consider what consequences their research might have in a wider, societal context.

National codes of conduct have been developed by the National Science Advisory Board for Biosecurity (NSABB), which published several recommendations and guidelines [31–37], including a toolkit for "promoting awareness and responsibility in dual use research" [34]. The Netherlands Code of Conduct for Biosecurity offers guidance but has to be implemented independently by institutions [38]. This code also recommends establishing a National Biosecurity Centre that would monitor scientific developments relevant to biosecurity, coordinate information and education, and carry out other networking and supportive functions.

Industry also has some codes of conduct. The International Association Synthetic Biology developed Best Practices in Gene Synthesis [39]. Their publication contains considerations for risk assessment and risk management regarding sequence analysis, but also recommends cooperation with national authorities in the case of potential illegalactivities.

Several international initiatives are working towards the goal of global biosurety—the Organization for Economic Cooperation and Development [40], the Global Health Security Initiative [41], the Australia Group [42], the Organization for Security and Cooperation in Europe [43], Pugwash Conferences on Science and World Affairs [44] and the WHO. Valuable resources can also be found at national institutions, notably the Fink Report [45] and the Lemon–Relman Report [46], both published by the US National Academies of Science.

The Fink Report names seven categories of research that warrant caution and calls for the implementation of institutional review boards. The NSABB was created as a consequence of the Fink Report. The Fink Report focuses on national structures and issues, whereas the Lemon–Relman Report deals with the same issues on a global level. It also focuses on freedom of research and exchange of information whilst supporting awareness-building and shared responsibility of scientists on an international level.

From the point of view of scientists, there are many reasons to be concerned when it comes to biosecurity. As biosafety is a prerequisite for most lab work, there are standard operating procedures, guidelines and laws governing the issue. These provisions can be developed on the basis of known facts about preventing infection and occupational health and safety rules. Furthermore, the usefulness and imperativeness of implementing sound biosafety measures is beyond controversy. However, biosecurity is a different matterand, for many laboratories and institutions, a new concern. Compared with the well-established field of biosafety, there are limited guidelines and regulations that deal explicitly with biosecurity. The availability of these guidelines depends crucially on the setting of the research. Traditionally, military research facilities already have high security standards compared with, for instance, a university laboratory. Furthermore, establishing biosecurity measures requires resources in terms of personnel and finances, and they might consequently hamper research. It is probable that additional biosecurity measures would have to be paid for with research funds, leavingless money for the actual research.

Time is another constraint that applies to both training and the conduct of research. University curricula are already filled; adding a new subject would require leaving something else out, and implementing biosecurity involves administrative efforts that become time-consuming. Furthermore, if a more comprehensive review becomes necessary, the details of a proposed project might have to be shared with other researchersin the field who are competitors.
Lastly, some researchers might not receive the visas needed for pursuing their research in laboratories abroad owing to security concerns. Similarly, cooperation might become impossible because security clearance cannot be obtained in all countries. Thus, implementing biosecurity is often perceived to have negative effects on the viability of projects, and related restrictions can lead to competitive disadvantages. This might prompt some scientists to move to countries with fewer constraints. In the light of these obstacles, how can we implement biosecurity with the least negative effects on research and scientific freedom?

The stakeholders involved have to agree on biorisk assessment, on the appropriateness of research projects and the limits to research. On the one hand, limiting scientific freedom would clash with good scientific practice, which is based on openness, accessibility and reproducibility. Furthermore, it could have negative effects on public health and health

care in general. On the other hand, concerns expressed by the security sector should be taken seriously.

These two communities—life sciences and the security sector—have to find common ground and be willing to adapt to a new situation, which is challenging for some. There are already concerns regarding the securitization of public health and the WHO [47]. In addition, many in the scientific community are doubtful whether secrecy would even be a suitable security measure [48]. In addition to bridging these differences in opinion, the two sectors need to find a common nomenclature and understanding on a global level when it comes to risk perception and assessment. So far, there is no measure to weigh security risks against benefits in other sectors such as public health, economics, science and even security benefits. Furthermore, those who assess the risks are often biased by different interests, experiences and perceptions. Therefore, it is imperative to have not only “breadth of expertise”, but also “breadth of perspective” [49].

A suitable path towards a global consensus would be an international code of conduct or ethics based on the WHO guidelines and further complemented by components from national codes. To gain global recognition for a fundamental code, all relevant bodies and institutions should be represented on a biosurety board. A representative assembly could be facilitated by a supranational and impartial organization such as the United Nations or the WHO. The WHO concept for biorisk management already takes naturally occurring diseases, laboratory accidents and deliberate releases into account, and is a comprehensive approach to biosurety. The concept is based on three pillars: research excellence, ethics, and biosafety and biosecurity. The suggested tools for biorisk management have different levels of strictness. They include research oversight mechanisms, the policies of funding agencies, publishers and editors, selected laws and regulations, codes of conduct and ethics, awareness-raising and educationalinitiatives [28].
Supplementing a global code of conduct with national codes of ethics and conduct would integrate existing domestic provisions and generate more specific codes. This restriction would allow us to focus on specific needs whilst taking into account available resources and infrastructure. Development of these codes should be initiated and managed by relevant stakeholders from academia, institutions, funding organizations and scientific societies. In some cases, existing national regulations could be reassessed and eventually restructured to reduce the strong compartmentalization seen in many regulatory agencies. Establishing independent national commissions for biosecurity could provide leadership for developing guidance, and provide the interface needed between science, securityand politics.

The next level of a comprehensive global biosurety network would be to commit organizations and institutions to establish specific codes. On this level, it would become feasible to develop concise guidance on how to assess biosecurity risks and DURC potentials, thus rendering the risk assessment less burdensome. Customized solutions would also allow the

inclusion of specific requirements, such as physical security on the basis of the actual facility. Furthermore, institutions or organizations should consider appointing a competent person or group who can provide advice and guidance on DURC issues, as not every individual within the institution can be expected to be an expert in the field.

Perhaps the most important step is to raise awareness and improve education about DURC, as stipulated in a report by ethics experts [13]. There are bio-safety officers at present, but there are hardly any designated offices or individuals in charge of biosecurity, or any formal training for biosecurity officers—there are only a few international training options. However, this might change in the future. There seems to be ample support for multinational training and the establishment of biosecurity networks that would improve global consensus-building and the exchange of experiences. A good example was set by a multidisciplinary course arranged by Public Health Canada and the Norman Paterson School of International Affairs at Carleton University, which combined international biosafety, dual-use biosecurity and bioethics [50]. If they cater to participants from many countries, such courses can both provide education and further international cooperation and trust-building. However, this was only one pilot course and it remains to be seen whether it will mature into a training option. Other resources include online training tools—for instance, those developed at the Office of Biotechnology Activities at the National Institutes of Health and NSABB [51].

Training requires qualified teachers and mentors. As the subject of biosurety is relatively new, there are only a few individuals capable of covering all aspects. Therefore, programmes for ‘training the trainers’ would have to be the first layer of implementing educational initiatives. Training the trainers is one issue, educating the scientific and security community is an even more challenging one. There are hardly any training opportunities for students; studies of university curricula have shown that biosurety issues are rarely addressed [52,53]. It is crucial to involve young academics in biosurety and offer appropriate training, as this will be an integral part of their career.

Laws, codes and guidelines cannot guarantee that all possible biosurety contingencies are adequately covered—individual responsibility and ethics are at least as important as legal provisions. Overall, implementing biosurety is a giant balancing act that we have to master in the near future: “Responsible decision-making is required by actors at all levels. Decision-makers will need to make judgements to resolve difficult cases of conflicting values. Scientific freedom, scientific progress, public health, safety and security are all important values, and none should be given absolute priority over the others. Conflict between these values, in any case, is not always inevitable” [28].

So, the question of whether society is protected from the malicious use of biological agents can, for now, only be answered conditionally. We still have to do some soul-searching and find consensus among the research

and security communities, among different kinds of research institutions and among nations. The results of these deliberations will hopefully lead to a comprehensive, globally harmonized, biosurety network.

Conflict of interest

The authors declare that they have no conflict of interest.

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