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Governing 'dual-use' research in Canada: A policy review

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National and international organisations have implemented governance mechanisms to address a diversity of ethical, security and policy challenges raised by advances in research and innovation. These challenges become particularly complex when research or innovations are considered 'dual-use', i.e. can lead to both beneficial and harmful uses, and in particular, civilian (peaceful) and military (hostile) applications. While many countries have mechanisms (i.e. export controls) to govern the transfer of dual-use technology (e.g. nuclear, cryptography), it is much less clear how dual-use research from across the range of academic disciplines can or should be governed. Using the Canadian research and policy context as case study, this paper will first, examine the governance mechanisms currently in place to mitigate the negative implications of dual-use research and innovation; second, compare these with other relevant international governance contexts; and finally, propose some ways forward (i.e. a risk analysis approach) for developing more robust governance mechanisms.

Keywords: dual-use research; governance; policy; regulations; Canada.

1. Introduction

After the Asian avian flu outbreak in 1997, researchers increased their efforts to better understand the H5N1 flu virus. But these research initiatives, some of which included the creation of hybrid mammalian–avian flu viruses, were said to have opened a 'Pandora's box' (Enserink 2004). In the process of working to better understand the virus, researchers experimented with the creation of more virulent strains, something that was accomplished in 2011 by teams in the USA (the Kawaoka team) and in the Netherlands (the Fouchier team). To prevent potential misuse—particularly with regards to bioterrorism—the US National Science Advisory Board for Biosecurity (NSABB) and the Dutch government recommended that part of this research not be published (Fidler 2012), and a temporary—but still on-going—moratorium on certain aspects of bird flu research was agreed to by researchers while issues of biosecurity could be discussed (Kelland and Nebehay 2012). The initial request to not publish and/or censor data in the Kawaoka and Fouchier papers created controversy in the scientific community, where the diffusion of research results is normally considered essential to the scientific process—i.e. to validate/invalidate research findings and 'truth' claims amongst the scientific community—and the basis for the advancement of knowledge (Fouchier et al. 2012). While the NSABB and the Dutch government eventually approved publication of the studies—published in the journals *Nature* (Imai et al. 2012) and *Science* (Herfst et al. 2012)—once again the controversial nature of the research brought academic and public policy attention to H5N1, both with regards to the issues of open scientific communication, freedom to publish (Enserink and Cohen 2012; Keim 2012a), and the need to regulate laboratory biosecurity standards (Enserink 2012; Keim 2012b).

Discussions about the need for (bio)security or regulatory measures for research that can present potentially serious risks to public safety are not exclusive to the health sciences (e.g. recombinant DNA, genomics); they are also relevant to many other areas of research in the natural sciences (e.g. nuclear energy, quantum theory), the applied sciences (e.g. data encryption, nanotechnology), and the social sciences (e.g. social marketing, cultural profiling). Scientific discoveries and technological innovations are rarely if ever 'neutral' or 'value-free', nor are they ever only 'good' or 'bad'. Instead, science and technology are invariably imbedded in complex social, cultural

and political contexts that shape how research findings and innovations are accepted, transformed or rejected by a range of actors, including researchers, industry, government and civil society (MacKenzie and Wajcman 1999; Webster 1991).

In the last few decades, many national and international organisations have implemented regulations and other governance mechanisms to address the socio-ethical, security and public policy implications of scientific research and innovation, often with the involvement of science policy advisory commissions, research ethics boards, or working groups of learned societies. Regardless of whether these diverse governance mechanisms are categorised as academic/scientific integrity, responsible conduct of research, academic accountability or research ethics, they share a concern for finding practical mechanisms to prevent misconduct and to promote ethical practices in academic research and technological innovation and application.

Yet, numerous difficult questions remain unanswered. When does a specific line of research or innovation become problematic (e.g. overly risky or harmful), and according to what values and from whose perspective? What responsibilities do researchers have (e.g. towards their governments or to society) beyond ensuring that their work meets the highest academic standards? What limits can or should institutions, funders or governments impose on academic freedom and knowledge dissemination in order to protect national security? When does a discovery or a technological innovation acquire good (beneficial) and/or bad (harmful) characteristics: all along the developmental pathway or only at application? Does the potential for harmful (bad) application negate the benefits (good) acquired during development? These challenges become particularly complex when, whether intentionally or unintentionally, research or innovations are considered 'dual-use', i.e. can lead to both beneficial and harmful uses (Bezuidenhout 2013), and in particular, civilian (peaceful) and military (hostile) applications (McLeish and Nightingale 2005).

Not surprisingly, many nations have regulations to control the transfer of technologies or material known to have dual-use civilian/military potential, e.g. through export controls and national or international monitoring. But what happens when the dual-use potential of a line of research, or of an innovation, is not evident or is unintended? Who should oversee or regulate the dissemination or transfer of scientific knowledge that may have dual-use potential and how should it be done? To begin addressing some of these questions, we present the Canadian research and policy context as a case study with which to examine the governance of dual-use research and innovation. This case is particularly interesting because Canada is a leader in both science and technology innovation (Government of Canada 2012; Government of Canada (Science Technology and Innovation Council) 2011), and in the development of research ethics and scientific integrity frameworks (Interagency Panel on Research Ethics 2010; Tri-Agencies 2011). Canada is also next to, and thus significantly influenced by, developments in the USA, where controversies about dual-use, security and open publication of science have been commonplace (National Science Advisory Board on Biosecurity 2012; Resnik 2010). While advisory boards and policies have already been created and implemented in the USA, Canada is still in the process of developing its stance on dual-use, which makes an analysis of its current policy context of particular interest.

In Canada, as in other developed nations (e.g. the USA, the UK), research and innovation occurs in both the private and public sectors. Thus it is likely that federal or provincial government departments or agencies (e.g. Defence R&D Canada, Public Safety Canada, Public Health Agency Canada), as well as industry (e.g. the pharmaceutical companies, engineering firms) are involved in various forms of dual-use research and innovation. For the purposes of this paper, we have chosen to focus our analysis on the governance mechanisms that could apply to research conducted in the academic context (e.g. research centres, universities). This limitation is justified by the diversity and quantity of research that occurs in the academic setting, but also by the important ethical challenges that arise when the norms of academic liberty and open science confront the need to regulate dual-use research and innovation.

In this paper, we provide a succinct overview of Canadian and international policies and mechanisms that can help mitigate the negative implications of dual-use research and innovation. Specifically, we describe how dual-use research and innovation is dealt with in Canada and internationally, and propose some points for consideration and ways forward for the development of more robust governance mechanisms.

2. Method

Between January and March 2012, we conducted a comprehensive interdisciplinary scoping review of the academic and grey literature (during the last ten years) in research ethics and scientific integrity, in order to situate current debates about dual-use research and innovation. Using a broad internet search (PubMed, Google/Google Scholar) for keywords such as 'dual-use', 'secondary use', 'weapons of mass destruction', 'biosecurity', 'export controls', and 'malevolent use', we selected more than 90 academic articles, reports and websites. The aim was to understand the history of 'dual-use' and its various applications (e.g. 'dual-use research', 'dual-use technology', 'dual-use dilemma', 'dual-use services'), as well as the ethical norms or principles at stake in reflections about why, how and who should govern dual-use research and innovation. We then performed a comprehensive mapping of research ethics, scientific integrity, and responsible

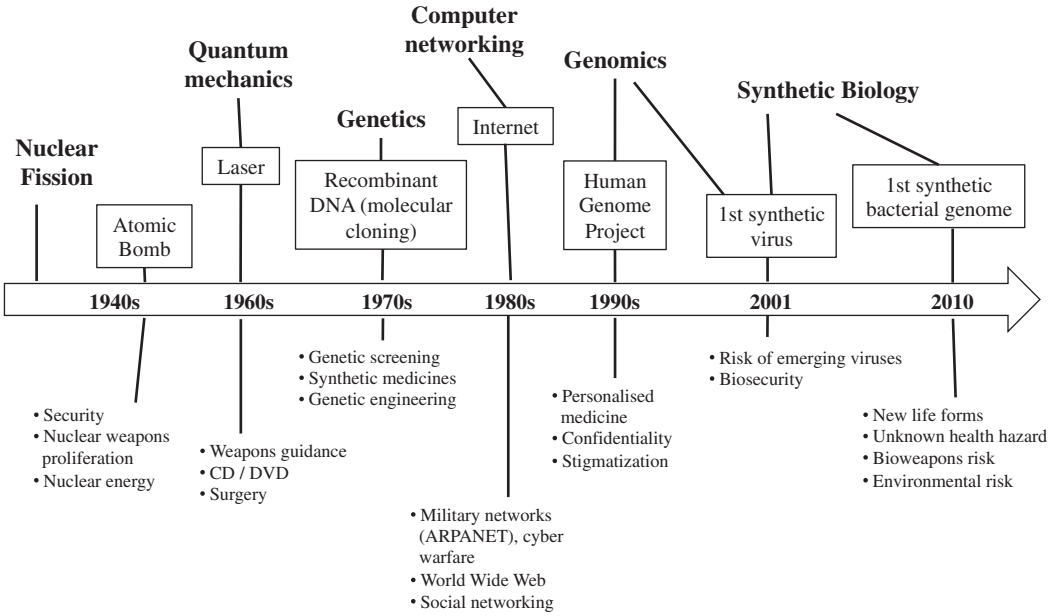

Figure 1. Discoveries/innovations with problematic dual-use potential.

conduct of research guidelines and frameworks in Canada, and compared these with other relevant international governance contexts (e.g. the USA, the EU, Australia), with a view to identifying particularities in Canadian governance mechanisms. This overview was limited to publicly accessible policies: unwritten practices or policies of a confidential/secret nature were excluded.

3. Defining 'dual-use': A historical overview

> In the last 100 years advances in science have dramatically increased the scientific research in all areas, which has been accompanied by a heightened awareness of the potential for the misuse/abuse of sensitive information and/or reagents and methodologies. The concept of dual-use came to a fore in the years leading up to the Second World War in the field of atomic sciences. The awareness that the same piece of research could be used for good as well as bad purposes led many scientists to question the ethical validity of their activities. (Bezuidenhout 2013: 84)

Historically, 'dual-use' has been defined as:

> . . . technology, equipment, and facilities that could be used for both civilian and military purposes. (Miller 2009: 23)

The focus has been on the downstream products of research in the nuclear sciences (Evans 2010), in information technology, and more recently in the biosciences (D'Agostino and Martin 2009). Much less attention has been paid to upstream elements of research (e.g. fundamental and applied research, information sharing) that are common to academic research and distant from real-world application. This focus on downstream dual-use innovations is evident when looking at past discoveries with dual-use potential (see Fig. 1 and Table 1).

From the outset, the motivation for defining dual-use involved a desire to restrict the scope of the term to a specific area of research or technology of concern, in order to develop guidelines or regulations to frame the conduct of such research or the use of particular technologies. While definitions of 'dual-use' are still a primary point of discussion and discord in the academic and policy communities, plausible definitions include research or science that:

> . . . has both civilian and military applications . . . (Fergusson 2009; Robinson 2012)

and/or that:

> . . . can be used for both beneficial/good and harmful/bad purposes. (Berns et al. 2012; Kuhlau et al. 2011)

The first definition is extremely wide in scope and so can include research that might not be problematic (e.g. research that leads to both legitimate military purposes and positive civilian applications, such as the internet). This definition is also descriptive and implicitly non-judgmental unless one views military applications of research—whether developed and used by nation states or terrorist groups—as negative and civilian applications as positive. The second definition is equally broad but explicitly normative. This raises the problem of determining criteria by which to judge research or innovations as 'beneficial' or 'harmful'. Furthermore, scholars such as Selgelid (2009) and van der Bruggen (2011) argue for the need to specify in definitions of dual-use, researchers' intentions and the possible consequences of research and innovations.

Table 1. Key historical events in dual-use research and innovation

Time period	Event
Beginning of 20th century	• Use of discoveries in chemistry and biology for development of weapons (mustard gas, chlorine during WWI) • Discovery of atomic fission and chain reaction
1940s	• Production and use of first atomic bomb • Research on biological weapons by USA, Russia, UK, Japan etc.
1940–90	• National technology policies were based primarily on national security. Economics was a secondary concern (Galev 2003)
After 1990	• Reorientation of technology policies towards a more global trading system (Galev 2003)
1990	• Human Genome Project begun, with goal of sequencing 95% of DNA in human cells during next 15 years
2001	• USA: September 11th attack elevates fear in population (aggravated by anthrax attack) • Australian researchers inadvertently showed that virulence of mousepox virus can be significantly enhanced
2002	• Researchers synthesize poliovirus from its chemical code (first synthetic virus)
2003	• USA: A panel of life science experts concluded that advances in biotechnology, coupled with difficulty in detecting nefarious biological activity, have potential to create a much more dangerous biological warfare threat (Office of Transnational Issues 2006)
2003	• Statement on scientific publication and security that potentially harmful publications should be modified or not published at all (Atlas 2009; Van Aken 2006)
2004	• Report: *Biotechnology Research in an Age of Terrorism* (National Research Council 2004) ○ Identified several classes of experiment 'that will require review and discussion [. . .] before they are undertaken or, if carried out' (Van Aken 2006) ○ Calls for self-governance of researchers and promotes codes of conduct ○ Creation of NSABB
2005	• Team of US scientists publish full sequence of highly virulent strain of influenza virus that caused Spanish influenza (Van Aken 2006)
2006	• US National Research Council report *Globalization, Biosecurity, and the Future of the Life Sciences* mentions the potential of dual-use in nanotechnology and synthetic biology
2007	• Extending host range (human → mouse) of *Listeria monocytogenes* by rational protein design
2008	• Israel: passes a Bill to enforce regulation of research into biological disease agents, promoting self-regulation of researchers. • Australia: Charles Sturt University and the Australian National University enforce mandatory training for dual-use • *World at Risk: The Report of the Commission on the Prevention of WMD Proliferation and Terrorism* (Graham et al. 2008) promotes bottom-up approaches (e.g. training for researchers)
2012 (16–17 February)	• WHO Geneva Meeting about H5N1 research and moratorium (Kelland and Nebehay 2012)

Following the approach taken by Selgelid (2009), we combine the above definitions and define 'dual-use' as:

> . . . research that may intentionally or unintentionally have both beneficial and harmful applications or consequences.

There are (at least) two levels of intention, i.e. that of the researcher/innovator and that of an end-user. A researcher/innovator may intend one purpose and not imagine that a user might transform the research or innovation for other purposes. Equally, a researcher may have no particular end-use in mind. We also expand somewhat the scope of dual-use by adding a clarification that it:

> . . . includes knowledge, processes, and technologies from the natural and applied sciences, the health sciences, and the social sciences.

This broader definition, we suggest, can better take account of research in the applied and social sciences that can or should be considered dual-use, and which has traditionally been ignored.

3.1. Examples from diverse fields of research

There are numerous examples in the literature about particular fields of research, largely in the natural sciences, and more recently in the biosciences, that raise dual-use concerns. Table 2 summarizes a broader range of examples, including some from the social sciences.

Table 2. Examples of dual-use research and innovation, by academic field

Example	Field	Beneficial use	Malevolent use
Nuclear research	Physics Biomedicine	• Nuclear energy • Radiology	• Nuclear weapons
Viral research (e.g. H1N1, H5N1)	Biosciences	• Public health (prevention) • Biodefence (prevention)	• Bioweapons (terrorism)
Synthetic biology (e.g. new genes, DNA)	Biosciences	• Biomedicine • Genetic enhancement	• Bioweapons
Nanotechnology	Converging fields: • Nanoscience • Bioscience • Information technology • Material sciences	• Biomedicine • Improved consumer goods	• Miniature weapons (nano-drones) • Surveillance society (miniature cameras)
Brain imagery and behaviour monitoring	Biosciences Cognitive psychology	• Biomedicine • Brain scans for criminal behaviour	• Behaviour monitoring and modification
Ethnographic profiling and marketing strategies	Social sciences	• Improved customer service	• Social profiling, marketing, behaviour modification

Although the term 'dual-use' has not been commonly used in the social sciences literature, this does not mean that research and applications in those disciplines cannot be used for both beneficial and harmful purposes, including military applications: there is, for example, growing discussion around the ethics of 'secondary use' in social science research.

Data and materials (e.g. interview recordings, videos, data sets) are research tools that support, enrich and stimulate the development of university research, the sharing of which aligns with a general movement promoting openness across the sciences for the benefit of society (Fischer and Zigmond 2010; Neylon and Wu 2009). It is possible to add value to important research resources by sharing them in the research community, by organising them in collections or by ensuring their commercialisation where possible (Grisé 2005). This value-added secondary use—be it scientific, social or economic—is increasingly important in our 'knowledge economies'. The development of knowledge and on-going technological innovations, previously seen as independent from the system of production and the marketplace, have become important factors in nations' economic viability (Peters 2008). Similarly, the term 'knowledge societies' has been used by UNESCO (2005) to define a society where knowledge benefits not only a population's economic needs, but also its social, ethical and political needs. However, promoting openness and sharing may also open the door for research, data and methods to be used for purposes that could be both beneficial and harmful.

There are numerous examples of research and innovations that can be or have been used for both malevolent and benevolent purposes. The most obvious is fundamental and applied research in nuclear physics that led to the creation of ground-breaking medical imaging equipment (e.g. X-rays and magnetic resonance imaging), cancer treatments such as radiation therapy, and powerful sources of energy for the community (e.g. nuclear reactors). The same science also led to the development of the atomic bomb, nuclear weapons, and radioactive contamination of the environment (e.g. Three Mile Island, Chernobyl, Fukushima).

Less obvious, but equally problematic even if the harms may be different, is research in nanotechnology, neurology and psychology, fields that individually or in combination can lead to research and innovation that can be put to both 'good' and 'bad' use. For example, brain implants used for deep brain stimulation (DBS) were developed in the 1980s and then commercialised by Medtronic to treat Parkinson's disease. By 1997, DBS had become a standard last resort treatment for Parkinson's, but was then extended for treatment of essential tremor, dystonia and obsessive compulsive disorder (OCD), and clinical trials are on-going for its use in the treatment of major depression that is refractory to medications (Bell et al. 2008). Given the technology's ability to treat, i.e. shape, 'deviant' social behaviour (e.g. OCD, some addictions), it is not unthinkable that DBS could stimulate research into other potentially contentious applications (Bell et al. 2009), such as enhancing cognitive performance or controlling the impulsiveness associated with criminality.

Continuing with chip technologies, radio frequency identification tags—which enable simple passive/semi-passive wireless data transfer—have become ubiquitous in consumer products of all sorts (e.g. to prevent shoplifting), in automatic toll systems, and in personal security (e.g. identification/access cards, passports). These chips have also been used as implantable devices (placed under

the skin) to track companion animals (Ntafis et al. 2008), and by extension, have been considered for human use in the management of dementia or Alzheimer's patients, and to track children and so monitor behaviour and prevent abduction (Wyld 2010), raising evident ethical and civil liberties concerns (Gasson et al. 2012).

On a different note, while ethnographic cultural research might enable researchers to develop a better understanding of a community, this knowledge can also lead to better ways of exploiting that same community through marketing (e.g. by industry) or ethnographic profiling (e.g. by government agencies). A classic example is the book by Condominas (1965), which was translated into English and read by the American military in their preparation for the war in Vietnam. Furious, Condominas added, in a preface to a subsequent edition, a vigorous denunciation of the American methods and their use of an ethnographic text to engage in the 'ethnocide' (a concept of Condominas) of the Mnong Gar people. Many other examples exist of social science research on sensitive topics (e.g. criminality, underground economies) or involving marginal and thus potentially vulnerable populations (e.g. Native or Aboriginal peoples; immigrant populations; the lesbian, gay, bisexual, and transgender communities), the results of which can both advance scientific knowledge and benefit these groups (e.g. through better access to government services or public recognition) but also put them at significant risk of discrimination (Homan 1991; Lee 1993). In some cases, social science researchers have made conscious decisions not to do certain types of research, or to refrain from publishing the results of research (or parts of research) that they judge to be sensitive and potentially damaging to their research participants. Such decisions remain contentious, given the importance of disseminating research findings as part of the process of knowledge production.

It is important, then, to recognise that 'dual-use' or 'secondary use' of research and innovation can arise in a diversity of fields. While attention should rightly be given to 'the usual suspects' of nuclear and bioscience research, dual-use implications of research in other areas (e.g. in the social sciences) should also be of concern.

3.2. Ethical norms, principles and challenges

Dual-use can be presented as a simple dichotomy or conflict between, on the one hand, ensuring national security (that is, public safety and public health), and on the other, protecting academic freedom or liberty and encouraging the pursuit of open science. However, the challenges and principles at stake in dual-use research are far more complex than this simple dichotomy. Table 3 presents, in a simplified fashion, some of the key ethical principles relevant to discussions about dual-use

Table 3. Norms and principles relevant in dual-use research

Rules and principles	Application	Implication
Precautionary principle	• Risk avoidance/prevention • Management	Focus on security at expense of academic freedom and open science
Purpose	• Goal of research/innovation • Oversight of some areas of research	Best intended actions can have unintended consequences • Issue of integrity
Responsibility/intention	• Individual researcher • Institution • Collective: academic community • Industry • Government	Determine responsibility (for what behaviour?) • Limits of responsibility, e.g. secondary use • Weighing principles, e.g. security, academic freedom, public good of research and innovation
Security	• Protect public health/security • State/researcher responsibility	Responsibility of researchers (e.g. biosecurity) and State • Conflicts over level of security required • Knowledge that researchers may lack
Academic freedom	• Interest driven research	Foundation of university research and innovation • When are limits justified? Who decides what research is legitimate, permissible?
Open science and sharing	• Data sharing • Publication and peer-review • Knowledge production	Foundation of university research and knowledge economy • Conflict between public good of knowledge or innovation and risk of misuse • When are limits justified? Who decides?
Beneficence and non-maleficence	• Goal of public research and innovation • State/researcher responsibility	Challenge defining what is beneficial or not harmful • Context specific? • Which metrics? Whose perspective?

research that were identified in our literature review, along with how these principles can be applied and their implications for governance and regulation.

If we look at the precautionary principle, for example, it has been widely used in European science policy-making with regards to environmental policies to protect biodiversity. This principle promotes the use of precautionary measures in cases where there is a:

> . . . threat or potential harm to human health or the environment even if the precise cause and effect relationships cannot be fully established scientifically. (D'Souza and Taghian 2010: 193)

While such measures can help avoid considerable harm, they can also have the adverse effect of limiting certain fields of inquiry if they slide from precaution to excessive prudence (e.g. censorship) (Weckert 2007).

In some cases, research (e.g. on H5N1 virulence) may be promoted even when there is a recognised level of risk, by examining researcher's intentions (is the goal to develop knowledge for malicious purposes?) and/or by giving multiple actors (e.g. government agencies, academic institutions) a responsibility to apply safety measures, such as biosecurity requirements. However, for even the best-intentioned researchers, and even when all appropriate safety measures are implemented, some aspects may still be overlooked, leading to accidents with potentially serious negative consequences (e.g. environmental contamination, publication of sensitive or confidential information). Moreover, the eventual use of the technology by badly intentioned actors may be difficult to anticipate.

In other cases, the risk to public health or national security may be determined to be sufficiently grave that the precautionary principle is applied, over and above an interest in the conduct of open science and knowledge production (Suk et al. 2011). This has lead most countries to implement strict controls on the publication and sharing of certain types of nuclear and cryptography research and technology (to be discussed in Section 4.1). Yet, because risk is invariably linked to scientific uncertainty, both with regards to the incidence and magnitude of potential harms, it can be argued that restricting certain behaviours (e.g. data or material sharing, publication) in order to protect the public's interest (e.g. public health, security) cannot outweigh the harm to academic liberty and open science, another public interest (especially when expressed through the language of the 'knowledge society' or 'knowledge economy'). The challenge, then, becomes one of measuring and weighing the different costs and benefits of various interests and the approaches needed to protect them.

Since the above-mentioned norms and principles each have their limitations (e.g. in terms of theory and application), they may be used in a mixed fashion, where different principles are brought to bear depending on the problem at hand. Using more than one approach may offset the weaknesses of another and provide more depth and further understanding of the problem at hand. It is important, however, to recognise that these principles need to be used in a context-specific way, that is, in a complex interrelation with other principles and potentially competing interests (e.g. academic freedom, public health/security, economic development) (Kuzma and Besley 2008). The application of these and other principles, norms, and guidelines will be explored further throughout this paper.

4. Research ethics and scientific integrity governance in Canada

In Canada, there are numerous regulatory mechanisms to promote academic integrity and the responsible conduct of research. These mechanisms include policies at all levels: public sector or governmental, institutional, and individual fields of research. The following sections will map out the mechanisms that could apply to dual-use research and innovation, as well as the actors involved.

4.1 Laws, regulations and policies

Trade agreements and export laws can have an effect on dual-use research and innovation. Since 'dual-use' has often meant 'military use', the export and trade of technology and components has been restricted to military allies, especially during times of conflict or imminent danger (Fuhrmann 2008). For example, as previously mentioned, nuclear research and cryptography has long been considered problematic and so classified as dual-use because of the potential harms of (mis)use by foreign powers. Since 1992, Canada has applied a 'dual-use mechanism' in order to have a framework to control the export of specific 'nuclear-related dual-use equipment, material and related technology' (Foreign Affairs and International Trade Canada 1994). This framework is enforced by the member nations of the Nuclear Suppliers Group (2012).[1] In Canada, for example, this includes the requirement to obtain an export permit from the Department of Foreign Affairs and International Trade, and an export license from the Atomic Energy Control Board, which are issued based on a series of conditions consistent with 'Canadian laws, regulations, policies and with Canada's multilateral and bilateral commitments' (Foreign Affairs and International Trade Canada 1994).

Canada has ethics and integrity policies that apply to publicly financed research, most notably the Tri-Agency Framework: Responsible Conduct of Research (TAF) (Tri-Agencies 2011) and the second edition of the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans (TCPS2) (Interagency Panel on Research Ethics 2010). While these policies do not refer specifically to 'dual-use', they do provide a broad regulatory framework for promoting academic integrity and ethical research, including possible dual-use research

(under our broad definition). For example, the TCPS2 requires researchers at institutions receiving grants from the one of the three federal funding agencies (the Natural Sciences and Engineering Research Council of Canada, the Canadian Institutes of Health Research, and the Social Sciences and Humanities Research Council of Canada) and who are conducting research involving human participants, to submit their projects for ethics review by a research ethics board (REB) at their host institution (e.g. university, research institute, hospital, medical research centre). The REB has the power to require modifications to proposals to ensure that the research meets the highest ethical standards, but this mandate is limited to research involving human participants. It should be noted, however, that the TCPS2 and the TAF apply only to research conducted in institutions receiving funds from one of the three federal granting councils. These guidelines do not apply to research conducted in government or industrial settings, unless the research is done in collaboration with university researchers; nor are there equivalent policies or ethics guidelines for government or private sector research. This creates a notable 'gap' in the current regulatory framework.

While the TAF covers the full range of publicly funded research, there is no equivalent oversight board (e.g. REB) required by this policy, nor mention of dual-use or concerns that ought to be addressed. Nonetheless, the TAF does point to related policies that address dual-use, including the Laboratory BioSafety Guidelines (Pathogen Regulation Directorate 2004), the Controlled Goods Program (Controlled Goods Directorate Administration 2001), the Canadian Nuclear Safety Commission Regulations (Canadian Nuclear Safety Commission 2009) and Canada's Food and Drug Act (Health Canada 2008). The Controlled Goods Program is of particular interest since it defines certain 'dual-use goods and technology' that must be registered with the Controlled Goods Directorate, in order to 'safeguard controlled goods within Canada and prevent controlled goods from being accessed by unauthorized persons'. However, these policies focus almost exclusively on 'technologies', 'products' or 'goods', and say very little about the conduct of 'research' or the dissemination of research findings.

4.2 Institutional guidelines

From our online search, Health Canada does not appear to have any publicly accessible policies or web pages that use the term 'dual-use'. Industry Canada does have specific web pages and policies, including: a policy on aerospace and defence (Industry Canada 2013), a web page on cyber security (Industry Canada 2008), and three web pages on cryptography policy (Industry Canada 2008, 2009a, 2009b, 2009c). Industry Canada also provides a performance report on the Canadian Biotechnology Strategy (Health Canada 2005), which includes the 'Establishment of a coherent and effective stewardship framework' in order to:

> Increase awareness and understanding of the nature and scope of the dual-use of technologies with respect to research in the biosciences and their current and potential impact on research practices and government policies. (Industry Canada 2008)

As might be expected, discussion of civilian–military dual-use was most prevalent at the Department of National Defence (50 web pages mention 'dual-use') and the Canadian Security Intelligence Service (14 web pages). Most of these web pages only briefly mention 'dual-use' and are linked to specific military technologies; they invariably neglect upstream research. Moreover, the term 'dual-use' is used in a descriptive manner that omits any normative judgment and thus does not provide guidance on what might be considered beneficial or harmful use.

We conducted an informal email survey of 15 Canadian research universities and identified only three that explicitly mentioned dual-use in their policies.[2] McMaster University's *Risk Management Manual* has a section entitled 'Controlled Goods and/or Controlled Technologies Program', the intention of which is to:

> ... provide a system and procedure for the responsible management under the Controlled Goods Program (CGP) of the Canadian Federal Government. (Risk Management Support Group 2009)

Memorial University of Newfoundland (2008) has a web page similar to the McMaster University risk policy, while the University of Alberta (2012) has a web page that includes examples of research or innovation that require an export permit for 'nuclear-related dual-use equipment or technology'. In these university policies, the term 'dual-use' is invariably associated with the CGP; as such, they mention applications and downstream innovations and do not explicitly address upstream dual-use research.

5. International guidelines and frameworks

Most national export control mechanisms have been developed to conform to the UN Security Council's prohibition on the acquisition, possession or use of nuclear, biological or chemical weapons by non-state parties. The Biological Weapons Convention in 1975, the Australia Group Arrangement in 1985, the Wassenaar Arrangement in 1994, and the Chemical Weapons Convention in 1997 all aim to control the spread and use of nuclear, biological or chemical weapons, as well as dual-use goods (Rappert 2008). None of these regulatory measures specifically discuss dual-use research. The risk that dual-use research poses for society has, however, long been recognised by international organisations such as UNESCO. In 1974, UNESCO specifically addressed the roles and responsibilities of researchers in the development of safe and responsible science while also pinpointing the

responsibility of governments to reduce the risk associated with dual-use research through national policies (UNESCO 1974). These policies must also recognise the free nature of science and the culture of academic liberty that is fundamental for the advancement of knowledge and scientific innovation (UNESCO 1999).

In the EU, the regulation of dual-use research has, as in other national contexts like Canada, focused on controlling dual-use exports (Molas-Gallart 2002). For example, EU Regulation 428/2009 (European Union 2009) forbids unauthorised export of selected dual-use items, and limits the transit of such items amongst EU states (Davis 2002). The 2006 EU Action Plan on Biological and Toxin Weapons requires regular reports of confidence building measures and investigations of alleged biological weapons development by EU states (European Union 2006), and there are a diversity of institutional actors broadly involved in controlling the proliferation of weapons of mass destruction and associated research (Grip 2011). Similarly, the UK's Anti-terrorism, Crime and Security Act (United Kingdom 2001) restricts the use of specific pathogens and toxins, and requires laboratory notification procedures. But it does not apply to novel organisms or synthetic compounds, leaving dual-use research (e.g. in synthetic biology) largely unregulated (McLeish and Nightingale 2005).

Since at least 2002, the Royal Society has been studying the implications of the misuse of scientific research (Davidson and Koppelman 2008). In 2009, the UK Parliamentary Office of Science and Technology suggested three measures to regulate dual-use research, all based on self-governance: first, prevention in scientific conduct (e.g. codes of conduct); second, prevention in dissemination of scientific research (e.g. censoring); and third, prevention in application of technology and innovation (e.g. monitoring of orders for dual-use goods) (Parliamentary Office of Science and Technology 2009). These measures identify researchers, funding agencies, and editorial boards as responsible for managing dual-use research and technology. The three major UK funding agencies involved in supporting health sciences research (i.e. the Biotechnology and Biological Sciences Research Council, the Medical Research Council and the Wellcome Trust) also developed joint measures to identify risks of misuse of scientific research in grant applications (Biotechnology and Biological Sciences Research Council et al. 2005). Finally, the OECD is also involved in producing relevant information and guidelines on biosafety/security (OECD 2012).

The USA has long been a leader in the development of dual-use policies and regulations (i.e. export controls). The 11 September 2001 attacks in New York and the 18 September 2001 Anthrax scare (Shea 2004) brought renewed attention to the risk of security breaches resulting from dual-use research and innovations (D'Agostino and Martin 2009). Reflections on how best to control dual-use research led the US government to conclude that restrictions were unfeasible without significantly impairing the development of beneficial science and technology, and thus would be an impediment to economic growth (National Research Council and American Association for the Advancement of Science 2009). In 2001, biosecurity requirements were included in the Patriot Act (P.L. 107-56) to control access to and use of certain biological agents for research (Shea 2004). Enforcement is the responsibility of the Centers for Disease Control, and relies mostly on whistleblowing and self-regulation.

The 2004 US National Research Council report (National Research Council 2004), identified seven classes of 'experiments of concern', including those that increase pathogen virulence, transmissibility, dissemination and resistance to current treatments or preventive measures. This led to the creation of the NSABB, which launched a working group on codes of conduct for dual-use research (Quirk 2004). In 2007, the NSABB proposed a 'Framework for the Oversight of Dual Use Life Sciences Research' (National Science Advisory Board for Biosecurity 2007), which was updated in 2012 and now includes a toolkit for addressing dual-use research (National Science Advisory Board on Biosecurity 2012). In these documents, the responsibility for addressing dual-use research concerns lies primarily with researchers, but without providing robust tools to support individual awareness raising and self-regulation. Some responsibility is given to US funding agencies, publishers and institutional review boards, but until very recently, no mention was made of specific government responsibilities to regulate dual-use research.

In March 2012, the US government announced a new policy (Department of Health and Human Services 2012), which requires federal agencies such as the National Institutes of Health to screen all research funding proposals for 'dual use research of concern'. As Malakoff (2012: 21) notes, this policy is:

> . . . the latest byproduct of the anthrax letter attacks that struck the United States in 2001 . . .

and has led the US to tighten its:

> . . . controls on research involving several dozen 'select agents'.

There are also governmental policies to control the export and sale of dual-use technologies and material (Office of Export Control Cooperation 2012), complemented by Project BioShield of America which oversees funding for the development and purchase of vaccines, therapies and diagnostic tools in response to public health emergencies (Buchanan and Kelley 2011).

5.1. Codes of ethics, disciplinary norms or statements

Codes of ethics, disciplinary norms or statements are mechanisms to define the ethical responsibilities of

individuals in an institution, a discipline or a field of research. For example, they may outline the social responsibility of the scientist to:

> . . . conduct research that they reasonably believe will result in a net benefit for society, and they should avoid conducting research that they have good reasons to believe would produce more harm than good for society. (Resnik and Shamoo 2005: 123)

National and international medical associations—such as the American Medical Association, the American Society for Biochemistry and Molecular Biology, and the World Medical Association—have included in their codes of ethics, or in separate policy statements, explicit mention of the responsibility of researchers to avoid the development of science with malevolent uses (American Medical Association 2004; Green et al. 2006; Rappert 2008). Although they have sometimes been called 'a weapon to counter bioterrorism' (Somerville and Atlas 2005), codes of ethics are unevenly distributed across disciplines and professions, and many academic or learned societies have not codified their ethical principles (Jones 2007). Moreover, outside the formal professions (e.g. medicine, nursing, engineering), codes of ethics are not legally binding and cannot constrain or mandate particular behaviours. So while codes of ethics, disciplinary norms and statements will be an important step in building awareness and a sense of responsibility regarding the good conduct of academic research and knowledge dissemination, their enforcement and overall impact may be rather limited.

5.2 Academic journals and societies

The publication of weapons development research and information about sensitive technologies (e.g. nuclear, cryptography) has long been restricted, especially when financed by defence departments (Cochrane 1978). While applicable to areas of national security, restrictive secrecy requirements are deeply unpopular in much of the academic community (Fischer and Zigmond 2010), because they:

- Undermine fundamental principles of science, such as the Mertonian norms of communalism, universalism, disinterestedness, originality and scepticism.
- Run counter to efforts by academic societies and funding agencies to promote open science that encourages the sharing of data, methods and results (e.g. public data repositories, open access journals, funding of knowledge transfer activities).
- Give excessive power to research funders (e.g. defence departments, private industry, funding councils) to control the design and conduct of research, thereby seriously restricting creativity and jeopardizing methodological rigour, and even placing researchers and their institutions in difficult conflicts of interest (e.g. between the interests of academic science and those of the research funders).

Some scholars promoting open science feel that the security benefits derived from government control of knowledge sharing and publication, for example, would actually weaken national security by hindering scientific advancement and so reduce the possibility of having the requisite knowledge and technologies in place to protect against potential dual-use applications (Petro 2004).

Nonetheless, journals in the applied and health sciences, such as *PNAS* or *Nature*, have begun developing guidelines on the publication of dual-use research (Cozzarelli 2003). Norms vary widely, however, and may include a diversity of approaches such as:

> 1) Do nothing, publish as is, 2) Edit the work to remove potentially harmful details and publish, 3) Publish with a commentary or editorial to place the work into context, 4) Reject on the basis that the security risk is too high. (Salsbury 2011: 97)

Furthermore, even if journals have an international readership, they operate within specific national legislative contexts and so must adhere to local policies regarding the publication of dual-use research, technology, methodology, data or material. Certain experts in research integrity, such as Resnik (2010), have advocated for the implementation of dual-use policies for all journals and the promotion of dual-use self-governance in the research community. In part, this focus on self-regulation is due to the recognition that national governments may be limited in their ability to require dual-use policies for journals, especially when the journals are based outside their jurisdiction. Finally, with the move to online open access publishing—and thus the rapid and widespread dissemination of research findings—the feasibility of international policy enforcement to control the publication of dual-use research may be rather limited.

6. Discussion

> Once we understand that the norms of 'open science' and the values that underlie them are not absolute, it becomes evident that the dual use problems should be reconceived as one aspect of a larger optimisation problem: how can policy, broadly understood, help shape the scientific enterprise in such a way as to give due weight both to its distinctive role in producing knowledge and to other relevant values, including, but not restricted to, the reduction of both dual use risks? (Buchanan and Kelley 2013: 196)

Our review of Canadian and international guidelines and regulations on dual-use research and innovation shows how different countries have developed various mechanisms to balance the need to support (and benefit from)

scientific research while also protecting populations against potential harms to health and security. Numerous policies have been instituted to control the export of dual-use technology and material, but they do not account for the risk caused by the dissemination of findings from dual-use research; as such, these policies can have only limited impact on the sharing of technology, material and knowledge that has become so common—even a fundamental principle—for the academic community. The reality is that it is much easier to regulate objects (products, agents, components) or even systems than it is to regulate ideas because the latter are not tangible, and so are easily accessible, transferable and diffused to a wide range of individuals, groups and states.

Apart from the NSABB framework in the USA, few national or international regulatory measures lay out detailed mechanisms or procedures to address the dual-use dilemma in research. For example, while the Australian National Framework for the Development of Ethical Principles in Gene Technology (Gene Technology Ethics Committee 2006) mentions avoiding the malevolent use of gene technology (Principle 8), it does not provide recommendations on how to manage such research. By contrast, the WHO (2008) suggests self-governance mechanisms for researchers and publishers (e.g. codes of conduct and restrictions on publications), and recommends the oversight of research and the licensing of researchers or facilities. As in the EU and the UK, the policy focus is on bioscience and nuclear science with little attention given to other fields of research where dual-use may be a concern. Thus, there is little in the way of comprehensive frameworks, regulations, or procedures to address the issues and concerns raised by dual-use research, in Canada or internationally. This lack of clear recommendations or guidelines is likely due to a lack of understanding and consensus amongst members of the academic and policy communities on the definition of 'dual-use research', as well as a widespread perception that dual-use relates exclusively to intentional weapons development.

In Canada, there are various policy and governance mechanisms to, on the one hand, ensure the ethical conduct of research in general (i.e. the TCPS2 and TAF), and on the other, control the development, export and exchange of dual-use innovations or technologies (e.g. export controls). But as should be evident, there will be no single institutional, national or international policy or governance mechanism that can address the full complexity and diversity of challenges raised by dual-use research and innovation. There are simply too many actors and stakeholders involved in the research process—itself a complex and non-linear pathway—and across a diversity of contexts (e.g. public and private research settings, institutions, oversight bodies) (see Fig. 2).

Given the complexity and diversity of academic research that may have dual-use potential and implications and the multiple contexts from which they result, very different ethical values, goals and interests will be at stake, some of which may conflict (see Fig. 3). It would be unreasonable to expect any one actor to be able to fully comprehend or be responsible for balancing the range of interests and values at stake (e.g. protection of public security in the context of a free sharing of knowledge). Thus, this points towards the need for a multifaceted and (ideally) coordinated approach to the governance of dual-use research in Canada and internationally that can address the different needs, interests, and limitations of the full diversity of actors involved (Bezuidenhout 2012). But it will be important to recognise that even a multifaceted approach will be imperfect. Scientific uncertainty, and the inability to perfectly understand potential risks and impacts (on health or security), will mean that there will be continued disagreement about

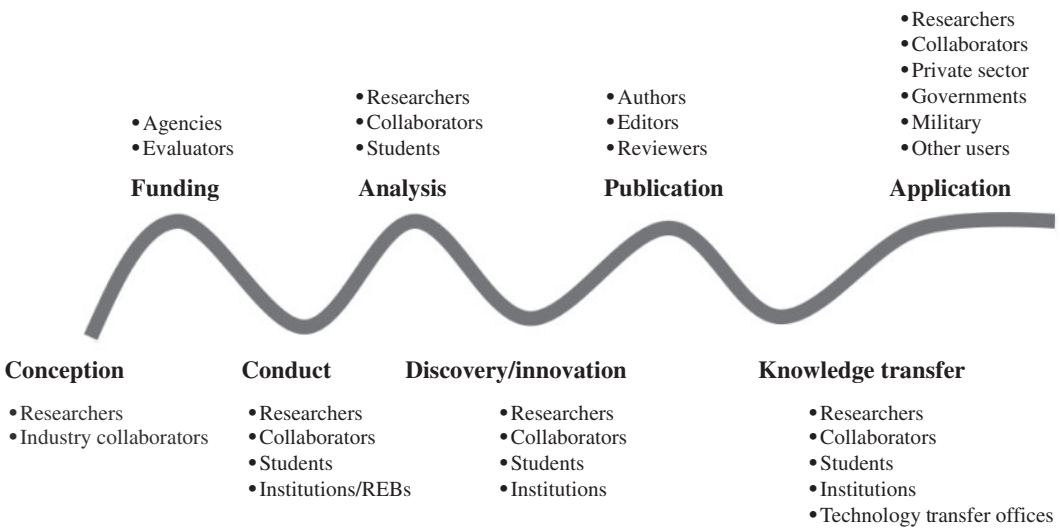

Figure 2. Steps and stakeholders in research process (adapted from National Science Advisory Board on Biosecurity 2012).

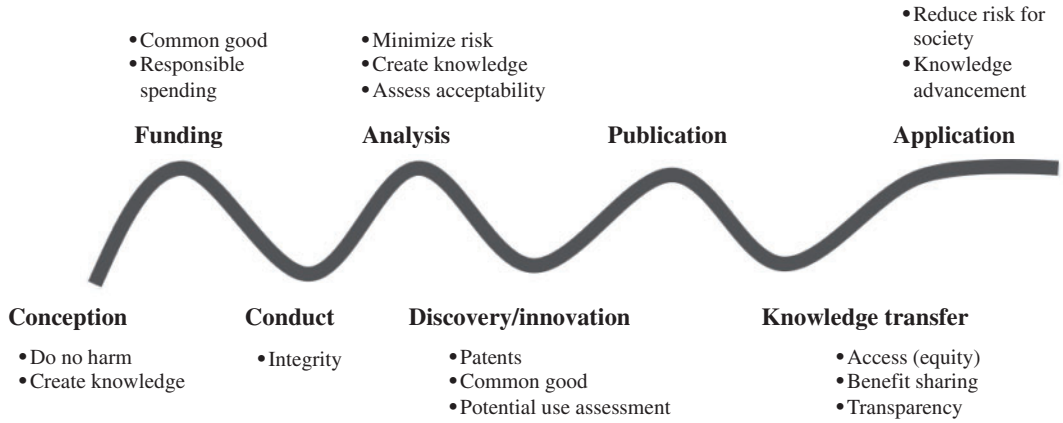

Figure 3. Ethical issues in research process (adapted from National Science Advisory Board on Biosecurity 2012).

Table 4. Risk thresholds and regulatory mechanisms for dual-use research and innovation

Risk	Example	Mechanism
Low or minimal	• Research that does not have any foreseen dual-use potential	• Full transparency/open publishing of research • Self-governance (societies, journals, associations)
Medium	• Genetics research • Ethnography • Nanotech research	• Codes of conduct (awareness) • Local and national review committees (like REBs)
High	• Nuclear research • Certain cryptography software	• Local, national, and international review committees • Government regulation/laws • International conventions

what constitutes the most appropriate approach to dealing with dual-use research or innovation in a particular context. Disagreements will have to be managed in such a way as to permit decisions to be made and actions taken, while still respecting as much as possible the interests of all stakeholders involved, including the academic community and the general public.

6.1 Possible ways forward

A starting point to better govern dual-use research in Canada, and internationally, could be a risk analysis approach that aligns the type of governance mechanism or intervention with the type of research or potential/eventual technology, such that the greater the risk, the more need there would be for formal regulation and oversight (see Table 4).

The TCPS2, the main research ethics policy document in Canada, defines minimal risk research:

> . . . as research in which the probability and magnitude of possible harms implied by participation in the research is no greater than those encountered by participants in those aspects of their everyday life that relate to the research. (Interagency Panel on Research Ethics 2010)

While there may not necessarily be 'participants' in dual-use research, this definition could be modified to help categorise minimal risk dual-use research. Yet, unlike the case of human subjects research where the identification of risks to participants may be foreseeable (e.g. risk of stigmatisation in culturally specific research, physical harm from the administration of pharmaceutical drugs), it may be difficult to name the potential harmful use or quantify its risk of occurrence for a type of research or innovation (e.g. foreseeable environmental risks), even more so if researchers or governing instances are not aware of the problem. This risk analysis approach can thus only be a first-level evaluation of dual-use potential, and will be an on-going process involving surveillance and education by a range of actors and regulatory systems, e.g. units within universities (biohazard committee), funding agencies (through peer-review committees, annual reports from researchers) and government institutions.

With these qualifiers in mind, we can modify the TCPS2 definition of minimal risk to apply to dual-use, as follows:

> . . . research in which the probability and magnitude of possible harms towards society is no greater than those encountered in everyday life.

Research or innovations meeting this definition would have no obvious or foreseeable potential dual-use application, would be placed in the low/minimal risk category, and so be governed by the tenets of open science, such as

full transparency of scientific methods and the open dissemination of research findings.

For research where there is a medium dual-use risk potential, the probability and magnitude of possible harms towards society is approximately equal to the benefits encountered by society. This could be the case of genetic research aiming to develop personalised medicines or 'designer babies', or ethnographic studies to understand the culture of vulnerable populations, which could also lead to discrimination or racial profiling. Mechanisms to reduce the risk of this type of research might include building awareness in the scientific community through education and academic codes of conduct, something that could be led by respected learned societies (e.g. the UK's Royal Society) and research funders, whether they be philanthropic (e.g. the UK Wellcome Trust) or government bodies (e.g. the Canadian Tri-Councils). Further, as experience with institutional review boards in the USA and REBs in Canada has shown in the context of research ethics, there is also an important place for local and national review committees to both evaluate the context-specific risks of particular research projects, and to participate in continuing education amongst the academic research community about the dual-use concerns raised by particular fields of inquiry and innovation.

Finally, research where the probability and magnitude of possible harms to society far outweigh the likely benefits would be categorised as high or serious dual-use risk. This would include nuclear physics and some types of biological research (e.g. on the synthesis of hybrid and/or virulent viruses), where the potential for accidental loss of control could have a devastating effect on a region or entire country (as in Fukushima, Japan). Such risks could, however, be greatly reduced through the imposition of strong precautionary mechanisms, such as government regulations, international conventions, as well as the aforementioned institutional mechanisms (e.g. review boards).

As is common with risk management strategies more generally, for the three risk categories, the mechanism used to govern dual-use research and innovation should be proportional to the probability and magnitude of harm. But for each type of governance mechanism, it will also be important to reflect on the particular advantages/disadvantages and interests for the various actors and stakeholders involved—and involve them in the determination of risk—and the applicability of the mechanism to a particular type of research or innovation (Hermansson and Hansson 2007). So for example, while export controls may be justified in high-risk dual-use research and innovation—such as some areas of nuclear physics, cryptography or bioscience—the limits imposed will nonetheless be very costly, both in terms of bureaucracy and restrictions on academic liberty and scientific progress. By contrast, in research that is purely conceptual, e.g. in philosophy or mathematics, the cost of imposing government control mechanisms would be disproportionate to the risk of dual-use, and so most probably unjustified. Table 5 presents a diversity of mechanisms that could be used to deal with particular dual-use situations, following a first general risk analysis (see Table 4). The possible governance mechanisms are ranked according to their level of coercion, from the least control to maximal control.

On the international stage, research ethics and scientific integrity in the context of dual-use research is generally a shared responsibility amongst policy-makers, public and private funding organisations, universities, REBs and researchers. These responsibilities are still unclear in Canada since they are rarely specified in policy, but responsibility will certainly differ depending on the actor, the context and the research process. National guidelines on dual-use research must reflect the reality of open science, but also recognise the risks associated with shared knowledge. Only multilevel collaboration amongst the actors and stakeholders involved can provide a justified management system for dual-use research and innovation.

6.2 Recommendations

6.2.1 Broaden and clarify the definition of 'dual-use'. Using a broader definition of 'dual-use' research, such as our proposition of:

> . . . research that may intentionally or unintentionally have both beneficial and harmful applications or consequences, including knowledge, processes, and technologies from the natural and applied sciences, the health sciences, and the social sciences.

This can help to move the discussion beyond an overly restricted focus on traditional military applications of the applied sciences and biosciences, to also include other disciplines, such as the social sciences. This will help ensure that the full range of pertinent research and technology is considered, something that is particularly important in a context of interdisciplinary research and convergence between once disparate bodies of knowledge (e.g. nanotechnology, psychology and neuroscience). A broad definition of dual-use research and innovation should also cover all steps of the research process, including 'upstream' conception and discovery, and not only the final 'downstream' publication or technological application.

6.2.2 Promote shared responsibility. It is essential to recognise that no one actor (individual, group, agency) can be fully responsible for identifying and managing problematic dual-use research and innovation. So while it is necessary that the key actors involved in research and innovation—i.e. researchers, institutions, journals and governments—are responsible for what they know and have the power to address (Kuhlau et al. 2008), they must also recognise the limits of their responsibilities and

Table 5. Possible governance mechanisms (adapted from Miller and Selgelid 2007)

Risk	Mechanism	Context/example	Advantages	Disadvantages
Low	Open science	• No restrictions on publication • 'Free market'	• Maximum liberty • Maximize innovation, public good	• No oversight or control • Can be complicit in serious harm
	Self-governance	• Recombinant DNA research (1970s) • Academic ethics, codes of conduct • Science societies, journals • Voluntary training, education	• Ensure liberty • Minimize restrictions • Academic buy-in • Build solidarity in academia • Public trust • Low cost • Adaptability to new discoveries	• Difficult to obtain widespread agreement except on general principles • Lack of specificity and efficacy of codes of ethics • Lack of security expertise • Limited enforceability
Medium	Institutional control	• Equivalent of REB or biosafety committee • Mandatory training/education (as for research ethics)	• Local oversight • Awareness of different research environments • Build on established mechanisms (research ethics) • Specificity to local context	• Conflicts of interest • Local enforceability • Bureaucracy and backlash • Impractical to screen all research • Lack of security expertise • Costly, burden on institutions
	Independent authority	• National oversight body	• Independent oversight • Less institutional conflicts of interest • Diversity of expertise	• Insufficient policing or enforcement powers
High	Government	• Regulatory agency • Ministries of Health, National Security	• Maximum oversight • Deploy expertise in security • Enforceability • Licensing • Prohibitions, restricted access, secrecy	• Maximize security at expense of innovation • Bureaucratic • Very costly • Impossible to implement comprehensively • Adapts slowly

the need to collaborate with the relevant actors (e.g. citizens).

6.2.3 Promote development of coordinated mechanisms. Academic institutions, national and international academic communities, learned societies, philanthropic organisations and government funding agencies, and governments should collaborate in the development of diverse but coordinated mechanisms—ranging from education and self-governance, to review committees and formal regulation—to address appropriately the issues and challenges raised by dual-use research and innovation. Given the different powers and responsibilities of the actors involved, this will require efforts at local, institutional, national and international levels.

6.2.4 Decentralisation and context-specific awareness/education. The Canadian and international academic communities should work to build awareness and educate their members about dual-use research and innovation, in research institutions, through disciplinary associations and learned societies, on editorial boards of scientific journals, and via funding bodies. It is important for all involved to recognise the real difficulty in identifying and evaluating the potential risk (likelihood and magnitude) of dual-use research and innovation. As such, raising awareness of the potential for dual-use in a diversity of research and innovation contexts becomes essential. This could take the form of mandatory courses for researchers (and regulators) on the implications of conducting high-risk dual-use research, as proposed in the USA (National Science Advisory Board on Biosecurity 2012). Voluntary mechanisms, such as participation in online courses by the academic community (Bollaert and Whitby 2012; Center for Science Technology and Security Policy 2012)—including students, researchers and REBs—and regular discussions at academic meetings (conferences, workshops) would also be important for building greater awareness on the issue of dual-use as it occurs across disciplines and fields of research, and how it can be managed appropriately.

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Notes

1. Member nations are: Argentina, Australia, Austria, Belarus, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Kazakhstan, Republic of Korea, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Turkey, Ukraine, UK, USA.
2. Few universities responded (3/15), and one stated that they had no knowledge of 'dual-use' policies. Emails were sent to either the research ethics and/or the research integrity offices, depending on the organisational structure of the university: Dalhousie University, Université Laval, McGill University, McMaster University, Queen's University, University of Alberta, University of British Columbia, University of Calgary, University of Manitoba, Université de Montréal, University of Ottawa, University of Saskatchewan, University of Toronto, University of Waterloo and University of Western Ontario.

References

American Medical Association. (2004) 'Guidelines to Prevent Malevolent Use of Biomedical Research', <http://www.ama-assn.org/resources/doc/code-medical-ethics/2078a.pdf> accessed 18 June 2013.

Atlas, R. M. (2009) 'Responsible conduct by life scientists in an age of terrorism', *Science and Engineering Ethics*, 15: 293–301.

Biotechnology and Biological Sciences Research Council, Medical Research Council and The Wellcome Trust. (2005) 'Managing Risks of Misuse Associated with Grant Funding Activities: A joint Biotechnology and Biological Sciences Research Council, Medical Research Council and Wellcome Trust Policy Statement', <http://www.wellcome.ac.uk/About-us/Policy/Policy-and-position-statements/WTX026594.htm> accessed 18 June 2013.

Bell, E., Mathieu, G. and Racine, E. (2008) 'The promises of deep brain stimulation in psychiatry', *Can Psychiatry Aujourd'hui*, 4: 1124–8.

—— (2009) 'Preparing the ethical future of deep brain stimulation'. *Surgical Neurology*, 72: 577–86.

Berns, K. I., Casadevall, A., Cohen, M. L., Ehrlich, S. A. *et al.* (2012) 'Adaptations of avian flu virus are a cause for concern', *Science*, 335: 660–1.

Bezuidenhout, L. (2013) 'Data sharing and dual-use issues', *Science and Engineering Ethics*, 19: 83–92.

——. (2012) 'Research infrastructures, policies and the "web of prevention": The ethical implications of inadequate research environments', *Medicine, Conflict and Survival*, 28: 19–30.

Bollaert, C. and Whitby, S. (2012) 'Online applied dual-use biosecurity education: A case study from the University of Bradford', *Medicine, Conflict and Survival*, 28: 59–71.

Buchanan, A. and Kelley, M. C. (2013) 'Biodefence and the production of knowledge: Rethinking the problem', *Journal of Medical Ethics*, 39: 195–204.

Canadian Nuclear Safety Commission. (2009) 'Laws and Regulations', (updated 7 November 2011), <http://nuclearsafety.gc.ca/eng/lawsregs/index.cfm%3E> accessed 18 June 2013.

Center for Science Technology and Security Policy. (2012) 'Workforce', <http://www.aaas.org/cstsp/programs/workforce.shtml> accessed 18 June 2013.

Controlled Goods Directorate Administration. (2001) 'The Controlled Goods Program', <http://ssi-iss.tpsgc-pwgsc.gc.ca/dmc-cgd/apropos-about/pltqus-plcs/cdr-frmwrk/cdr-frmwrk-eng.html> accessed 18 June 2013.

Cochrane, R. C. (1978) *The National Academy of Sciences: The First Hundred Years, 1863–1963*. Washington, DC: National Academy Press, <http://www.nap.edu/catalog.php?record_id=579> accessed 18 June 2013.

Condominas, G. (1965) *L'Exotique est quotidien: Sar Luk, Vietnam central*. Paris: Pion.

Cozzarelli, N. R. (2003) 'PNAS policy on publication of sensitive material in the life sciences', *Proceedings of the National Academy of Sciences*, 100: 1463.

D'Agostino, M. and Martin, G. (2009) 'The bioscience revolution and the biological weapons threat: Levers and interventions', *Globalization and Health*, 5, <http://www.globalizationandhealth.com/content/5/1/3> accessed 18 June 2013.

D'Souza, C. and Taghian, M. (2010) 'Integrating precautionary principle approach in sustainable decision-making process: A proposal for a conceptual framework', *Journal of Macromarketing*, 30: 192–9.

Davidson, N. and Koppelman, B. (2008) *Royal Society Activities on Reducing the Risk of the Misuse of Scientific Research*, RS Policy Document 17/08. London: Royal Society, <http://royalsociety.org/policy/publications/2008/misuse-scientific-research/> accessed 18 June 2013.

Davis, I. (2002) *The Regulation of Arms and Dual-Use Exports: Germany, Sweden and the UK*. Oxford, UK: OUP and Stockholm International Peace Research Institute.

Department of Health and Human Services. (2012) *United States Government Policy for Oversight of Life Sciences Dual Use Research of Concern*. Washington, DC: US Government, <http://oba.od.nih.gov/oba/biosecurity/pdf/united_states_government_policy_for_oversight_of_durc_final_version_032812.pdf> accessed 18 June 2013.

Enserink, M. (2004) 'Tiptoeing around Pandora's box', *Science*, 305: 594–5.

——. (2012) 'Public at last, H5N1 study offers insight into virus's possible path to pandemic', *Science*, 336: 1494–7,

<http://www.sciencemag.org/content/336/6088/1494.full> accessed 18 June 2013.

—— and Cohen, J. (2012) 'One of two hotly debated H5N1 papers finally published', *Science*, 2 May 2012, <http://news.sciencemag.org/sciencenow/2012/05/one-of-two-hotly-debated-h5n1-pa.html?ref=em> accessed 18 June 2013.

European Union. (2006) 'EU Action Plan on Biological and Toxin Weapons, Complementary to the EU Joint Action in Support of the BTWC', *C57-2* (9.3.2006 edn.; European Union: Official Journal of the European Union).

——. (2009) 'Community Regime for the Control of Exports, Transfer, Brokering and Transit of Dual-Use Items', *Council Regulation No 428/2009* (European Union, L 134/2; EU: Official Journal of the European Union).

Evans, N. G. (2010) *Dual-Use Bioethics: The Nuclear Connection*. United Kingdom: Centre for Applied Philosophy and Public Ethics (CAPPE), an Australian Research Council Special Research Centre, <http://www.brad.ac.uk/bioethics/media/SSIS/Bioethics/docs/Nuclear SciencesWP.pdf> accessed 18 June 2013.

Fergusson, I. F. (2009) *The Export Administration Act: Evolution, Provisions, and Debate*, Washington, DC: CRS Report for Congress, <http://www.fas.org/sgp/crs/secrecy/RL31832.pdf> accessed 18 June 2013.

Fidler, D. (2012) 'Risky research and human health: The influenza H5N1 research controversy and international law', *American Society of International Law*, 16, <http://www.asil.org/pdfs/insights/insight120119.pdf> accessed 18 June 2013.

Fischer, B. A. and Zigmond, M. J. (2010) 'The essential nature of sharing in science', *Science and Engineering Ethics*, 16: 783–99.

Foreign Affairs and International Trade Canada. (1994) 'Export Controls on Nuclear and Nuclear-related Dual-use Equipment, Materials and Related Technology', <http://www.international.gc.ca/controls-controles/systems-systemes/excol-ceed/notices-avis/72.aspx> accessed 18 June 2013.

Fouchier, R. A. M., Herfst, S. and Osterhaus, A. D. M. E. (2012) 'Restricted data on influenza H5N1 virus transmission', *Science*, 335: 662–3.

Fuhrmann, M. (2008) 'Exporting mass destruction? The determinants of dual-use trade', *Journal of Peace Research*, 4: 633–52.

Galev, T. (2003) 'Questioning the 'dual-use' concept'. Paper presented at IAS-STS Work-in-Progress Workshop, held 13 March 2003, Graz, Austria.

Gasson, M. N., Kosta, E. and Bowman, D. M. (2012) 'Human ICT implants: From invasive to pervasive'. In: Gasson, M. N., Kosta, E. and Bowman, D. M. (eds), *Human ICT Implants: Technical, Legal and Ethical Considerations*, pp. 1–8. The Hague: T. M. C. Asser Press.

Gene Technology Ethics Committee. (2006) *National Framework for the Development of Ethical Principles in Gene Technology*. Canberra, Australia: Department of Health and Ageing, Office of the Gene Technology Regulator, <http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/content/gtecpapers-1/$FILE/gtecethicalprinc.pdf> accessed 18 June 2013.

Government of Canada. (2012) 'S&T Data 2010: Canada and the World', <http://www.science.gc.ca/S&T_Reports/S&T_Data_2010/Canada_and_the_World-WS5DF6DBC3-1_En.htm> accessed 18 June 2013.

Government of Canada (Science Technology and Innovation Council). (2011) *State of the Nation 2010 - Canada's Science, Technology and Innovation System*. Ottawa, ON: Science, Technology and Innovation Council Secretariat, <http://www.stic-csti.ca/eic/site/stic-csti.nsf/vwapj/10-059_IC_SotN_Rapport_EN_WEB_INTERACTIVE.pdf/$FILE/10-059_IC_SotN_Rapport_EN_WEB_INTERACTIVE.pdf> accessed 18 June 2013.

Graham, B., Talent, J. M. and Allison, G. T. (2008) *World at Risk: The Report of the Commission on the Prevention of WMD Proliferation and Terrorism*. New York: Vintage Books.

Green, S. K., Taub, S., Morin, K. and Higginson, D. (2006) 'Guidelines to prevent malevolent use of biomedical research', *Cambridge Quarterly of Healthcare Ethics*, 15: 432–9.

Grip, L. (2011) *Mapping the European Union's Institutional Actors Related to WMD Non-proliferation* 1: EU Non-Proliferation Consortium), pp. 1–20, <http://mercury.ethz.ch/serviceengine/Files/ISN/135141/ipublicationdocument_singledocument/388210ae-ded8-431b-8f63-dbc3e3c83017/en/EUNPC_no+1.pdf > accessed 18 June 2013.

Grisé, A. (2005) *La valorisation de la recherche universitaire - Clarification conceptuelle*. Quebec, Canada: Secrétariat du Conseil de la science et de la technologie, <http://www.mesrst.gouv.qc.ca/fileadmin/contenu/publications/conseil_science_techno/etudes_analyses/2005_e01_recherche_fevrier.pdf> accessed 18 June 2013.

Health Canada. (2005) 'Canada's Biotechnology Strategy', <http://www.hc-sc.gc.ca/sr-sr/biotech/role/strateg-eng.php> accessed 18 June 2013.

——. (2008) 'Canada's Food and Drugs Act & Regulations' (updated 7 July 2008), <http://www.hc-sc.gc.ca/fn-an/legislation/acts-lois/act-loi_reg-eng.php> accessed 18 June 2013.

Herfst, S., Schrauwen, E. J., Linster, M., Chutinimitkul, S. *et al.* (2012) 'Airborne transmission of influenza A/H5N1 virus between ferrets', *Science*, 336: 1534–41.

Hermansson, H. and Hansson, S. O. (2007) 'A three-party model tool for ethical risk analysis', *Risk Management*, 9: 129–44.

Homan, R. (1991) *The Ethics of Social Research*. London: Longman.

Imai, M. *et al.* (2012) 'Experimental adaptation of an influenza H5 HA confers respiratory droplet transmission to a reassortant H5 HA/H1N1 virus in ferrets', *Nature*, advance online publication, <http://dx.doi.org/10.1038/nature10831> accessed 18 June 2013.

Industry Canada. (2008) 'Performance Report: For the Period Ending March 31, 2006', (updated 29 October 2010) <http://www.ic.gc.ca/eic/site/ic1.nsf/eng/01398.html> accessed 18 June 2013.

——. (2009a) 'Electronic Commerce in Canada; International Forums - Cybersecurity', (updated 19 August 2008), <http://www.ic.gc.ca/eic/site/ecic-ceac.nsf/eng/gv00487.html> accessed 18 June 2013.

——. (2009b) 'Electronic Commerce in Canada; Cryptography', (updated 6 March 2009), <http://www.ic.gc.ca/eic/site/ecic-ceac.nsf/eng/h_gv00085.html> accessed 18 June 2013.

——. (2009c) 'Electronic Commerce in Canada; Part 2: Cryptography Policy in Canada Today', (updated 10 March 2009), <http://www.ic.gc.ca/eic/site/ecic-ceac.nsf/eng/gv00366.html> accessed 18 June 2013.

——. (2013) 'Aerospace and Defence', (updated 30 January 2013), <http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/home> accessed 18 June 2013.

Interagency Panel on Research Ethics. (2010) *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*. Ottawa: Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Social Sciences and Humanities Research Council of Canada, <http://www.pre.ethics.gc.ca/eng/policy-politique/initiatives/tcps2-eptc2/Default/> accessed 18 June 2013.

Jones, N. L. (2007) 'A code of ethics for the life sciences', *Science and Engineering Ethics*, 13: 25–43.

Keim, B. (2012a) 'Controversy continues after engineered-bird-flu study published', *Wired*, 2 May 2012, <http://www.wired.com/wiredscience/2012/05/engineered-h5n1-published/> accessed 18 June 2013.

—— (2012b) 'Lab security standards raise chances of mutant-bird-flu catastrophe', *Wired*, 2 May 2012, <http://www.wired.com/wiredscience/2012/05/engineered-h5n1-security/> accessed 18 June 2013.

Kelland, K. and Nebehay, S. (2012) 'Decision time for researchers of deadly bird', *Reuters*, 14 February 2012, <http://www.reuters.com/article/2012/02/14/us-birdflu-who-meeting-idUSTRE81D0W820120214> accessed 18 June 2013.

Kuhlau, F., Eriksson, S., Evers, K. and Hoglund, A. T. (2008) 'Taking due care: Moral obligations in dual use research', *Bioethics*, 22: 477–87.

——, Höglund, A. T., Evers, K. and Eriksson, S. (2011) 'A precautionary principle for dual use research in the life sciences', *Bioethics*, 25: 1–8.

Kuzma, J. and Besley, J. C. (2008) 'Ethics of risk analysis and regulatory review: From bio-to nanotechnology', *NanoEthics*, 2: 149–62.

Lee, R. M. (1993) *Doing Research on Sensitive Topics*. London: Sage.

MacKenzie, D. and Wajcman, J. (eds) (1999) *The Social Shaping of Technology*, 2nd edn. Philadelphia, PA: Open University Press.

Malakoff, D. (2012) 'US agencies to start acreening biomedical proposals for dual use', *Science*, 336: 21.

McLeish, C. and Nightingale, P. (2005) 'The impact of dual use controls on UK science: Results from a pilot study', *SPRU Electronic Working Paper Series*, 132, <https://www.sussex.ac.uk/webteam/gateway/file.php?name=sewp132&site=25> accessed 18 June 2013.

Memorial University of Newfoundland. (2008) 'Controlled Goods', <http://www.mun.ca/policy/site/policy.php?id=103> accessed 18 June 2013.

Miller, S. (2009) 'Ethics engagement of the dual-use dilemma: Progress and potential'. In: Rappert, B. (ed.) *Education and Ethics in the Life Sciences: Strengthening the Prohibition of Biological Weapons*, pp. 23–43. Canberra: ANU E Press, <http://epress.anu.edu.au?p=51221> accessed 18 June 2013.

—— and Selgelid, M. J. (2007) 'Ethical and philosophical consideration of the dual-use dilemma in the biological sciences', *Science and Engineering Ethics*, 13: 523–80.

Molas Gallart, J. (2002) 'Coping with dual-use: A challenge for European research policy', *JCMS: Journal of Common Market Studies*, 40: 155–65.

National Research Council. (2004) *Biotechnology Research in an Age of Terrorism (Fink Report)*. Washington, DC: National Academy Press, <http://www.nap.edu/openbook.php?isbn=0309089778> accessed 18 June 2013.

National Research Council and American Association for the Advancement of Science. (2009) *A Survey of Attitudes and Actions on Dual Use Research in the Life Sciences: A Collaborative Effort of the National Research Council and the American Association for the Advancement of Science*. Washington, DC: National Academy Press, <http://www.nap.edu/catalog.php?record_id=12460> accessed 18 June 2013.

National Science Advisory Board for Biosecurity. (2007) *Proposed Framework for the Oversight of Dual Use Life Sciences Research: Strategies for Minimizing the Potential Misuse of Research Information*. Washington, DC: NSABB, <http://oba.od.nih.gov/biosecurity/pdf/Framework%20for%20transmittal%200807_sept07.pdf> accessed 18 June 2013.

National Science Advisory Board on Biosecurity. (2012) *Enhancing Responsible Science; Considerations for the Development and Dissemination of Codes of Conduct for Dual Use Research*. Washington, DC: NSABB, <http://oba.od.nih.gov/oba/biosecurity/documents/COMBINED_Codes_PDFs.pdf> accessed 18 June 2013.

Neylon, C. and Wu, S. (2009) 'Open science: Tools, approaches, and implications', Pacific Symposium on Biocomputing, 14: 540-544, <http://psb.stanford.edu/psb-online/proceedings/psb09/workshop-opensci.pdf> accessed 18 June 2013.

Ntafis, V., Patrikakis, C. Z.., Fragkiadaki, E. G. and Xylouri-Fragkiadaki, E. M. (2008) 'RFID application in animal monitoring'. In: Yan, L., Zang, Y., Yang, L. T. and Ning, H. (eds), *The Internet of Things: From RFID to the Next-Generation Pervasive Networked Systems*, pp. 165–84. Boca Raton, FL: Auerbach Publications.

Nuclear Suppliers Group. (2012), <http://www.nuclearsuppliersgroup.org/Leng/default.htm> accessed 18 June 2013.

OECD. (2012) 'Science and technology: Biosafety - BioTrack', <http://www.oecd.org/env/ehs/biotrack/> accessed 18 June 2013.

Office of Export Control Cooperation. (2012) 'Overview of the U.S export control system', <http://www.state.gov/strategictrade/overview/>, accessed 18 June 2013.

Office of Transnational Issues. (2006) *The Darker Bioweapons Future*, OTI SF 2003-108. Washington, DC: Central Intelligence Agency, <http://www.fas.org/irp/cia/product/bw1103.pdf> accessed 18 June 2013.

Parliamentary Office of Science and Technology. (2009) 'The dual-use dilemma', *Postnotes*, 340, <http://www.parliament.uk/documents/post/postpn340.pdf> accessed 18 June 2013.

Pathogen Regulation Directorate. (2004) *Laboratory Biosafety Guidelines*, 3rd edn, 5 March 2012. Ottawa: Health Canada, <http://www.phac-aspc.gc.ca/lab-bio/res/blk-acb/lbg-ldmbl-eng.php> accessed 18 June 2013.

Peters, M. A. (2008) 'Education and the knowledge economy'. In: Hearn, G. and Rooney, D. (eds), *Knowledge Policy: Challenges for the 21st Century*, pp. 27–44. Cheltenham, UK: Edward Elgar.

Petro, J. B. (2004) 'Intelligence support to the life science community: Mitigating threats from bioterrorism', *Studies in Intelligence*, 48: 57–68.

Quirk, M. (2004) 'USA establishes advisory board for 'dual use' research', *The Lancet Infectious Diseases*, 4: 258.

Rappert, B. (2008) 'The benefits, risks, and threats of biotechnology', *Science and Public Policy*, 35: 37–43.

Resnik, D. B. (2010) 'Can scientists regulate the publication of dual use research?', *Studies in Ethics, Law, and Technology*, 4: 1–7, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3134283/> accessed 18 June 2013.

—— and Shamoo, A. E. (2005) 'Bioterrorism and the responsible conduct of biomedical research', *Drug Development Research*, 63: 121–33.

Risk Management Support Group. (2009) *Risk Management Manual: Controlled Goods and/or Controlled Technologies Program* RMM #507. Hamilton, ON: McMaster University, <http://www.workingatmcmaster.ca/med/document/RMM-507-Controlled-Goods-Program-1-36.pdf> accessed 18 June 2013.

Robinson, J. (2012) 'Space security through the transatlantic partnership', *Space Policy*, 28: 61–3.

Salsbury, D. (2011) 'Editors must be aware of dual-use research', *Science*, 34: 97–8.

Selgelid, M. J. (2009) 'Dual-use research codes of conduct: Lessons from the life sciences', *NanoEthics*, 3: 175–83.

Shea, D. (2004) *Dual-Use Biological Equipment: Difficulties in Domestic Regulation*. Washington, DC: Congressional

Research Service, The Library of Congress, <http://www.ndu.edu/library/docs/crs/crs_rs21422_22jan04.pdf> accessed 18 June 2013.

Somerville, M. A. and Atlas, R. M. (2005) 'Ethics: A weapon to counter bioterrorism', *Science*, 307: 1881–2.

Suk, J. E., Zmorzynska, A., Hunger, I., Biederbick, W. *et al.* (2011) 'Dual-use research and technological diffusion: Reconsidering the bioterrorism threat spectrum', *PLoS Pathogens*, 7: e1001253. <http://www.plospathogens.org/article/info%3Adoi%2F10.1371%2Fjournal.ppat.1001253> accessed 18 June 2013.

Tri-Agencies. (2011) *Tri-Agency Framework: Responsible Conduct of Research*. Ottawa, ON: Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, Social Sciences and Humanities Research Council of Canada, <http://www.rcr.ethics.gc.ca/eng/policy-politique/framework-cadre/> accessed 18 June 2013.

UNESCO. (1974) 'Recommendation on the status of scientific researchers', in General Conference of the United Nations Educational, Scientific and Cultural Organization, 17 October to 23 November 1974. UNESCO (ed.), Paris: UNESCO. <http://portal.unesco.org/en/ev.php-URL_ID=13131&URL_DO=DO_TOPIC&URL_SECTION=201.html> accessed 18 June 2013.

——. (1999) 'Declaration on science and the use of scientific knowledge', in Proceedings of World Conference on Science held Budapest, Hungary, 29 June–1 July 1999, UNESCO and International Council for Science (eds). Paris: UNESCO. <http://www.unesco.org/science/wcs/eng/declaration_e.htm> accessed 18 June 2013.

——. (2005) *Towards Knowledge Societies*. Paris: UNESCO, <http://unesdoc.unesco.org/images/0014/001418/141843e.pdf> accessed 18 June 2013.

United Kingdom. (2001) 'Anti-terrorism, Crime and Security Act', Chapter 24 (UK).

University of Alberta. (2012) 'Travelling with field equipment', <http://www.fieldoffice.ualberta.ca/en/Equipment/TravellingwithFieldEquipment.aspx> accessed 18 June 2013.

Van Aken, J. (2006) 'When risk outweighs benefit', *EMBO Reports*, 7: S10–13, <http://www.nature.com/embor/journal/v7/n1s/full/7400726.html> accessed 18 June 2013.

van der Bruggen, K. (2011) 'Possibilities, intentions and threats: Dual use in the life sciences reconsidered', *Science and Engineering Ethics*, 18: 741–56.

Webster, A. (1991) *Science, Technology and Society: New Directions*. New York: Palgrave.

Weckert, J. (2007) 'An approach to nanoethics'. In: Hodge, G. A., Bowman, D. M. and Ludlow, K. (eds), *New Global Frontiers in Regulation: The Age of Nanotechnology*, pp. 49–66. Cheltenham, UK: Edward Elgar.

World Health Organization. (2008) 'Research Policy and Management of Risks in Life Sciences Research for Global Health Security', Report of the meeting, 10-12 December 2007. Bangkok, Thailand. <http://whqlibdoc.who.int/hq/2008/WHO_HSE_EPR_2008.4_eng.pdf> accessed 18 June 2013.

Wyld, D. (2010) 'Preventing the worst case scenario: An analysis of RFID technology and infant protection in hospitals', *Internet Journal of Healthcare Administration*, 7, <http://www.ispub.com/journal/the-internet-journal-of-healthcare-administration/volume-7-number-1/preventing-the-worst-case-scenario-an-analysis-of-rfid-technology-and-infant-protection-in-hospitals.html> accessed 18 June 2013.