

Do new Ethical Issues Arise at Each Stage of Nanotechnological Development?

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Abstract The literature concerning ethical issues associated with nanotechnologies has become prolific. However, it has been claimed that ethical problems are only at stake with rather sophisticated nanotechnologies such as active nanostructures, integrated nanosystems and heterogeneous molecular nanosystems, whereas more basic nanotechnologies such as passive nanostructures mainly pose technical difficulties. In this paper I argue that fundamental ethical issues are already at stake with this more basic kind of nanotechnologies and that ethics impacts every kind of nanotechnologies, already from the simplest kind of engineered nanoproducts. These ethical issues are mainly associated with the social desirability of nanotechnologies, with the difficulties to define nanotechnologies properly, with the important uncertainties surrounding nanotechnologies, with the threat of ‘nano-divide’, and with nanotechnology as ‘dual-use technology’.

Keywords Ethics · Equity · Dual-use technology · Generations of nanotechnologies · Informed consent · Nano-divide · Nanotechnologies · Precautionary principle · Risk · Social desirability · Uncertainty

Introduction

The literature regarding ethical issues associated with nanotechnologies has become prolific. Many topics are at stake: the governance of nanotechnologies, the existence of nanoethics as a field on its own, health and environmental issues, ethical responsibilities of nanotechnology researchers, the blurring between categories such as nature and artefact, etc. However, the International Risk Governance Council has argued in its *White paper on nanotechnology risk governance* that fundamental ethical problems arise only with rather sophisticated nanotechnologies, whereas more basic nanotechnologies mainly pose technical difficulties [10]. It appears though that fundamental ethical issues are already at stake with basic nanotechnologies. The objective of this paper is to highlight these ethical problems and thereby to show that ethics impacts all types of nanotechnologies.

The paper is structured as follows. First I will introduce Roco’s typology of generation of nanotechnologies (“Generations of Nanotechnologies”). Then, I will present a conception, which assumes that ethics plays a role mainly from the second generation of nanotechnologies (“A Common Conception: Ethics from the Second Generation of Nanotechnologies”). In a third part, I will review the main ethical issues arising from this second generation of nanotechnologies (“Specific Ethical Issues Associated with the 2nd, the 3rd and the 4th Generations of Nanotechnologies”). Next, I will show that, beyond these specific issues, there are fundamental

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ethical problems, which are already at stake with first generation nanotechnologies (“Ethics in Generation 1”). Finally, I will proceed to the conclusion (“Conclusion”).

Generations of Nanotechnologies

The term “nanotechnologies” designates both relatively simple nanomaterials such as stain-resistant cotton fabrics or tennis balls, and very complex—and hypothetical—technologies that are supposed to redefine the future of mankind, such as brain implants that would enhance human capacities. In fact, it includes an extremely wide range of potential applications—food, chemicals, personal care products, medical devices, water quality, and so on ([11], p. 8). It seems thus unrealistic to think of ‘nanotechnologies’ as a single technology and to consider all the different types of applications at once. In this perspective, distinctions have been made in order to characterize the different types of applications at stake, the main differentiation criteria being whether they are currently available or envisioned for the future ([15], p. 98): some authors speak of ‘near term’ and ‘advanced’ nanotechnology, some of ‘incremental’, ‘evolutionary’ or ‘radical’ nanotechnology, while others introduce the idea of ‘generations of nanotechnologies’.

Mihail Roco has proposed this latter framework, with four overlapping generations of nanotechnologies (Fig. 1), which are progressively introduced over time [25]. In a more recent paper, he has also added converging technologies on the timeline, which are supposed to appear after generation 4 [26].

- *First-generation nanotechnologies* correspond to passive nanostructures—passive because the behaviour of the material is supposed to be steady over time. Most frequently, it consists in adding a nanomaterial to another material in order to improve its performances. It is the case of materials with specific properties such as cosmetics or coatings—for example antibacterial materials based on nanosilver. Most of the current applications of nanotechnologies belong to this first generation.
- *Second-generation nanotechnologies* are active nanostructures, which change their behaviour according to their environment. These active structures are thus able to perform functions, such

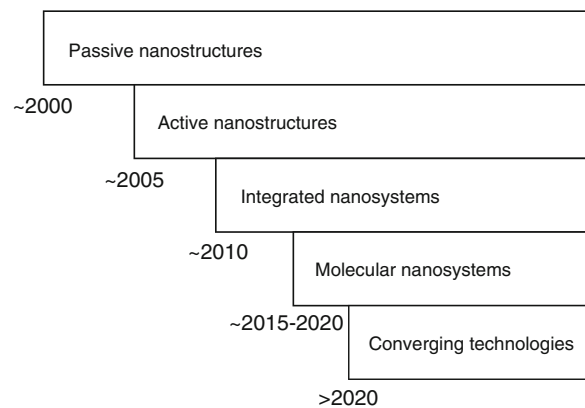


Fig. 1 Generations of nanotechnologies—inspired from ([26], p. 433)

as targeting drugs to specific parts of the body. Targeted cancer therapies illustrate concretely this second generation of nanotechnologies.

- *Third-generation nanotechnologies* correspond to integrated nanosystems, in other words ‘systems of nanosystems’, such as artificial organs built from the nanoscale. According to Roco, these are supposed to be developed from now on.
- *Fourth-generation nanotechnologies* are anticipated to be heterogeneous molecular nanosystems, ‘where each molecule in the nanosystem has a specific structure and plays a different role’ [25]. It would include macromolecules ‘by design’, nanoscale machines and interfaces between humans and machines at the tissue and nervous system levels ([7], p. 11). They are supposed to emerge from 2015/2020.
- *Converging technologies* will be technologies resulting from the convergence of NBICs technologies (Nanotechnologies, Biotechnologies, Information technologies and Cognitive science) such as nano-bio-info from nanoscale, cognitive technologies or large complex systems from nanoscale ([26], p. 433).

It is worth noting that the distinction between generations 2, 3 and 4 is rather unclear: as Davies notes, ‘even knowledgeable experts have expressed difficulty distinguishing among Roco’s last three generations’ ([7], p. 11).

Does Roco’s speculative project leave a space for ethics? If the answer is yes, when should ethics play a role?

A Common Conception: Ethics from the Second Generation of Nanotechnologies

Several authors emphasize the role of ethics only from the second generation of nanotechnologies.

For example, during the ‘J3N (national network in nanosciences and nanotechnologies, France) days’ in 2006, Françoise Roure presented passive nanostructures as being the source of ‘traditional’ toxicological or ecotoxicological risks without posing further ethical problems, which were recognized to be relevant from the stage of active nanostructures [27].

It is also the position of the International Risk Governance Council, in the *IRGC white paper on nanotechnology governance* [10]. This is a founding paper, written by Ortwin Renn and Mihail Roco, which proposes a conceptual risk governance framework at the international level. A more thorough analysis appears thus to be relevant. Their framework refers to two frames of reference for the categorisation of nanotechnology evaluation. These frames are based on the evolution of knowledge, the level of complexity and the potential social and ethical consequences: frame 1 considers passive nanostructures, whereas frame 2 considers active nanostructures, integrated nanosystems and heterogeneous molecular nanosystems ([10], p. 33).

More precisely, frame 1 corresponds to the context of classical technology assessment, looking into the physical impacts of the application of first generation nanotechnologies ([10], p. 37–41). In this frame, the risk appraisal stage focuses on classical risk assessment, where the usual toxicological and epidemiological methods can be applied.

On the other hand, frame 2 ‘addresses the context of social desirability of innovations looking into processes of technical modernisation, changes in the interface between humans and machines/products and ethical issues concerned with the boundaries of intervention into the environment and the human body’ ([10], p. 37–38). Beyond the focus on classical risk assessment, the risk appraisal stage focuses here on ‘concern assessment’, which corresponds to an assessment of risk perception and the societal context of risk. Scientific methods of concern analysis, empirical attitude, value research and ethical reasoning are thus more appropriate to frame 2 ([10], p. 41).

In the same vein, at the risk communication level, the *White paper* suggests to distinguish between the risk communication programmes for each of the two

frames: ‘the first communication strategy (for both frames 1 and 2) should be designed to enlighten the discussion about the benefits and non-intended side effects and the means to identify and quantify those effects. (...) The second strategy (particularly for frame 2) should be directed towards a broader debate on the desirability of special applications of nanotechnology in the light of ethical and social issues (...)’ ([10], p. 61).

Even though ethics is implicitly embedded in frame 1,¹ it is clear that, for the authors, the core of ethics lies is frame 2: ‘the ethical implications of nanotechnology development on risk governance are particularly important for frame 2’ ([10], p. 39–40). However, we will see that fundamental ethical issues are already at stake with the development of passive nanostructures. Before that, let us review the main ethical questions associated with active nanostructures, integrated nanosystems and heterogeneous molecular nanosystems.

Specific Ethical Issues Associated with the 2nd, the 3rd and the 4th Generations of Nanotechnologies

This section summarizes the recurrent ethical issues linked to the 2nd, the 3rd and the 4th generations of nanotechnologies, which can be found in the literature.

Many ethical issues are associated with the advancements in nanomedicine (second and third generations of nanotechnologies), insofar as they might possibly threaten the principles of equity, of autonomy, of privacy and data protection, and of safety and responsibility. Indeed, the development of medical applications of nanotechnology will inevitably exacerbate the question of access to treatments and thus equity and distributive justice issues. These will arise within developed countries, for example with the improvements of targeted cancer therapies that only the richest patients will be able to afford, but also between developed and developing countries ([1], p. 191), with new medicines that will help to prevent HIV infection specially

¹ For example, when the authors ask the question of how much precaution is necessary when producing the nanomaterials and their potential applications ([10], p. 14), or when they acknowledge that ‘political and security risks’ and ‘educational gap risk’ are raised with the development of first generation nanotechnologies ([10], p. 15).

needed in the developing world, which will be unable to afford these. The principle of autonomy is also at stake as, in some cases, nanotherapies might possibly be used without the informed consent of the patient. Moreover, medical surveillance will lead to privacy and data protection issues. Lab-on-chip technologies designed to facilitate medical diagnosis and screening, and the decoding of genetic dispositions could become commonly used. The question of who will have access to the resulting medical records—employers? insurance companies?—will then of course arise ([1], p. 192). Finally, safety and responsibility issues will arise from the emergence of implantable drug delivery nanochips, of nanoparticles that can release on demand pharmaceuticals, or of nanochips, which will be able to provide early diagnosis. The control and the reversibility of these technologies, which are supposed to be able to evolve within their environment, are at stake, especially because it is currently not well understood how these might interact with the body. In this context, what can go wrong and who is supposed to be responsible if something goes wrong are two questions that need to be answered.

The right to privacy and the protection of personal data could be threatened in general, beyond the question of the protection of medical information. Indeed, with the emergence of nanochips, the problems already at stake with other information technologies are exacerbated. As van den Hoven and Vermaas put it, ‘RFID foreshadows what nano-electronics has in store for our privacy: invisible surveillance’ ([36], p. 292). With nanotechnologies, information systems will have a greater ability to retrieve data about someone without the person knowing it ([35], p. 217). More speculatively, nanosensors could be implanted in the human body without informing the individual about it. Thereby, they could literally lead to spy on individuals. Beyond the threat to the right to privacy and to individual freedom, some fear for human dignity as these nanochips could lead to the manipulation of the individual’s will and behaviour [6].

Issues associated with human enhancement [18, 19] are also susceptible to arise with and after the development of the third and fourth generations. Human enhancement is indeed the explicit agenda of the National Science Foundation program *Converging Technologies for Improving Human Performance* [21], which considers the convergence of NBICs. In this perspective, converging technologies could be used to

modify the physical, cognitive or emotional capacities of human beings. The question of the legitimacy of human enhancement is at stake, as such technological developments would have a price: not only will they inevitably lead to equity problems [4, 8], human dignity issues, but they will also challenge elements of our symbolic order [34] and involve threats to fundamental representations such as human nature [5, 13], threats which are inherent to ideologies such as transhumanism.

Moreover, metaphysical questions are susceptible to arise with the hybridization of living and lifeless. Indeed, the distinction between the categories of nature and artefact are blurred as soon as we consider the elementary building blocks of the living or of nature as machines or devices.² In the same vein, the boundary between human and non-human will also become indistinct with the modification of human beings at the nano level. The blurring of these categories implies also ethical consequences, as they lead to the questions surrounding the patentability of nanoproducts involving life forms—or even human beings.

More generally for generations 2, 3 and 4, the question of public involvement is acknowledged to be at stake. There is, for the first time, a demand coming from governmental agencies for public debates about nanotechnologies before the start of a massive public opposition to these. However, and regrettably, such efforts are possibly made in order to pre-empt oppositions such as in the case of nuclear power or GM foods, and to secure public support for these developments. The proposals of Roco and Renn can be interpreted in such a way, when they say ‘if (...) risk perception is not based on the best available knowledge, innovative opportunities may be lost’ ([10], p. 15). As Bensaude-Vincent puts it, it is fundamental, for nanotechnologies promoters, to provide the conception and the production of new artefacts with a ‘social engineering’, which would prepare the society upstream to accept these innovations [6]. This leads to the fact that, implicitly, we are still facing a ‘top-down’ approach, where the promoters are imposing innovations to citizens, considered as passive

² ‘Science publique’, radiobroadcast from *France Culture* by Michel Alberganti (26th of June 2009), interview of Bensaude-Vincent, B. Faut-il craindre la technoscience? Retrieved on April 15, 2011, from <http://www.fabriquedesens.net/Faut-il-craindre-la-technoscience>

consumers [6]. The manipulation of the social demand raises of course many ethical questions, as does the instrumentalization of the social debate.

Ethics in Generation 1

Besides these ethical issues that arise from generation 2, crucial ethical questions appear already with the development of passive nanotechnologies even though the IRGC *White paper* does not give them any priority. These are intertwined with social, legal, economic and environmental issues.

This section highlights these main issues confronting first generation nanotechnologies. It takes as a starting point specific problems posed by nanotechnologies: the question of the social desirability of first generation nanotechnologies, the ethical issues associated with the difficulties to define nanotechnologies properly, the ones linked to uncertainties surrounding nanotechnologies, the threat of ‘nano-divide’, and the ethical issues linked to nanotechnology as ‘dual-use technology’.

Questioning the Social Desirability of First Generation Nanotechnologies

As a reminder, in the *IRGC white paper on nanotechnology risk governance*, Roco and Renn insisted on the necessity, for generations 2, 3 and 4, to question the desirability of special applications of nanotechnology in the light of ethical and social issues ([10], p. 61). If it is acknowledged that such an upstream approach is needed from generation 2, these fundamental questions were avoided in the case of generation 1. However, the question of the social desirability is also legitimate in this case—all the issues mentioned in “Ethics in generation 1” are contributing to the justification of such a debate. Avoiding the debate on the desirability of first generation nanotechnologies has implicitly led to impose these technological developments, which are not necessarily corresponding to social needs or public aspirations ([12], p. 29).

As some of these nanoproducts are already on the market, the focus is on their potential risks. In this context, the utilitarian framework of risk/cost/benefit analysis, based on the evaluation of consequences at the economic level as well as at the levels of health

and safety, is the most common framework invoked for the evaluation of nanotechnologies, even though framing the debate in terms of risks and benefits appears rather reductionist. Indeed, it allows to consider the principles of beneficence and non-maleficence, but it neglects many other ethical principles such as the principles of autonomy, justice and integrity ([16], p. 150), which should also be taken into account. A pure consequentialist stance appears to be insufficient and should be balanced by deontological arguments, based on individuals’ fundamental rights and duties. This is however a more general debate, which falls beyond the scope of this paper.

Furthermore, the fact that the question of the desirability of first generation nanotechnologies has been avoided is all the more embarrassing considering the fact that no particular labelling is currently required for nanotechnologies. Hence, even at the individual level, the citizen is not able to make a choice when consuming nanoproducts—consumption, which happens without him knowing it.

Finally, the public interest issue of social desirability of nanotechnologies is closely related to the question of research funding, which is of course already at stake with the development of generation 1. Indeed, the funding of research in the field of nanotechnology leads to ask who is supposed to decide upon the orientation of public research. This issue is of paramount importance in the case of nanotechnologies, considering the significance of the funding at stake. If it leads to cut the budget allocated to other projects that are ethically and socially desirable—such as the ones related to health care, education or sustainable development—then this choice should be justified ([1], p. 190). More generally, it is the question of the link between the orientation of public research and the citizens’ demands, which is at stake [14].

Ethical Issues Associated with the Difficulties to Define Nanotechnologies Properly

The crucial question of the definition of nanotechnologies is also at stake, insofar as it is at the origin of several ethical problems.

The question that arises is how to define nanos as substances, which are different from their non-nano-equivalent? Intuitively, the size comes to mind first when we have to distinguish nano from non-nano. Usually, we speak of nanotechnologies when at least one

dimension of the product is smaller than 100 nm. However, this 100 nm limit may seem somewhat arbitrary ([15], p. 98). Indeed, it is not obvious that 100 nm is the typical size when the properties of the materials start changing: for some properties, there is a gradual transformation and for others, there are thresholds below which the properties change suddenly ([3] p. 3). Hence it is not sure that 100 nm has a significant biological relevance ([31], p. 91). Besides, relying on this yardstick does not allow to take into account neither particles with specific properties—different from the bulk material—but with a size slightly above 100 nm, nor aggregates of nanoparticles, which would also exceed 100 nm. Another problem comes from the fact that relying solely on the particles size is insufficient: other specific physical features—such as shape—also influence drastically their properties. In the same vein, the environment of the particles and the fact that they may be associated with other components play also an important role in defining their characteristics.

Yet, in order to develop a regulatory framework specific to nanotechnologies, we need to give an existence at the statutory and at the legal levels to these objects [17]. Therefore, we need to be able to define their identity, which appears to be currently very problematic. Let us illustrate the kind of ethical and regulatory problems proceeding from these definition difficulties.

The labelling issue is arising in a specific way in the case of nanotechnologies. Indeed, taking into account only the chemical substance is insufficient: the size of the particles plays also a role in defining toxic properties, as well as other characteristics such as shape. It is therefore difficult to label nanoproducts ([17], p. 102). This is rather problematic as ‘the key ethical concept related to risk and risk imposition is the notion of consent’, with the classic conditions required to ensure free and informed consent being disclosure, understanding, voluntariness and competence ([32], p. 49). Yet in the case of nanotechnologies, the lack of proper disclosure of their risks and uncertainties impedes the possibility, for the citizen, to make a free and informed choice.

In the same perspective, we may wonder how to demand the application of the precautionary principle, often invoked in the name of the safety and sustainability principles, when we are unable to define the products at stake. This is particularly embarrassing considering that the huge uncertainties surrounding nanotechnologies

might precisely require the application of the precautionary principle—this point is developed in the next section.

Ethical Issues Associated with Uncertainties Surrounding Nanotechnologies

We know that nanomaterials are characterized by chemical, physical, electromagnetic and biological properties that differ from the bulk structure composed of the same chemical elements – and it is precisely the uniqueness of these properties that makes nanotechnologies so attractive. Hence, their toxicity is also very different from bulk particles. It is particularly the case when the toxicity itself is the property that is useful, such as in the case of nanosilver, which is bactericide. However, currently, the knowledge about the processes involved is very limited and the uncertainties are of paramount importance.

Under these conditions, is it ethically justifiable to develop and to market such products? How can we make sure that the principles of safety and sustainability are not jeopardized? This leads of course directly to the question of the precautionary principle. In order to show more concretely why it is the case, let us review some of the main uncertainties associated with nanotechnologies.

With engineered passive nanoparticles, we are facing safety, environmental and health issues. If these risks seem to be pretty close to classical chemical risks in their nature—as these technologies are supposed to behave steadily over time—their understanding is limited and they raise many epistemic issues.

At the safety level, we know, for example, that the higher surface reactivity and surface-area-to-volume ratio of nanoparticles increase the risk of dust explosions and the ease of ignition ([10], p. 43). However, the processes involved are not well understood yet.

At the environmental level, there is also a great deal of uncertainty. The impact of nanoparticles may be significant because of the potential for ([10], p. 44):

- bioaccumulation: due to their high mobility, nanoparticles can easily move in the air, water and soil, contaminate the fauna and flora and thus be transferred to the food chain;
- persistence: creating non-biodegradable pollutants, which will be hard to detect, might lead to an important waste problem—even though

nanotechnologies are often presented as being intrinsically ecological.

Concerning health risks, it seems, at first sight, that classical risk assessment procedures can be conducted. It is the viewpoint of the International Risk Governance Council, amongst others [11]. However, the situation is not so simple, as many uncertainties surrounding nanotechnologies imply both theoretical and practical problems, which makes it difficult to apply these classical risk assessment procedures.

One first practical problem comes from the fact that current measurement techniques are not sensitive enough to measure the concentration of nanoscale substances ([31], p. 40–41). Measurements are thus not widely available and advancements in nanometrology are clearly needed.

There is also a great deal of uncertainty about how nanomaterials can penetrate the body (through inhalation, ingestion, contact) and about their accumulation ([23], p. 255).

Another challenging problem specific to nanotechnologies comes from the fact that it is not obvious how exposure relates to toxicity: it is unclear how the chemical composition, the size, the shape, the surface area, the surface chemistry, the crystal structure and many other characteristics affect the toxicity of nanomaterials ([22]; [31], p. 42). Whereas, traditionally, the chemical composition is sufficient to determine the toxicity of a substance, the problem is much more complex in the case of nanotechnologies from an epistemic standpoint. In fact, there seems to be a shift of paradigm in the field of toxicology as long as, with nanotechnologies, it is impossible to determine once for all ‘the right criteria’ to take into account in order to assess nanotechnologies risks ([17], p. 79). This undermines a recommendation that is often made, which consists in requiring a standardized procedure. Here, it seems that a case-by-case approach would be needed, even if it would be practically very difficult to conduct considering the pace and the important number of new nanoproducts that are put on the market. More generally, in fact, there cannot be a generic approach to health, environment and safety regulation insofar as, with the development of science and technologies at the nanoscale, there will always be new kinds of effects and new kinds of potential problems ([33], p. 17).

If we are willing to determine the social acceptability of nanotechnologies through a risk/cost/benefit

analysis, other difficulties arise. Indeed, this classical utilitarian approach appears to be very problematic insofar as the risks are not only largely unknown, but also the benefits are difficult to assess ([23], p. 254; [20], p. 45).

We can thus see why all these uncertainties make nanotechnologies an ideal candidate for requiring the precautionary principle, although, as mentioned before, the difficulties to define nanotechnologies properly hinder the application of this principle.

Such a precautionary approach—that Europe is in principle willing to adopt—comes up against the ‘accomplished fact’ policy, as several types of nanoparticles are already on the market [6], even though several agencies and societies such as the Afssa (Agence française de sécurité sanitaire des aliments), the Afsset (Agence française de sécurité sanitaire de l’environnement et du travail) or the Royal Society ([28], p. 85) have been trying to blow the whistle about these risks and uncertainties.

On the other hand, a strong version of the precautionary principle in the form of a moratorium or pure abstention is not approved unanimously, which is not surprising given the business interests that are at stake and given the potential benefits of the development of nanotechnologies. However, a precautionary approach does not necessarily imply the kind of decision that would be implemented through new or stricter laws [18]. Indeed, another way to introduce precaution in the development of nanotechnologies would be to improve our evaluation of these materials through the development of new testing methods and the elaboration of new standards, which can be integrated into existing laws ([18], p. 12). This is precisely Lin’s point, who shows a way to take proportionate action in this context. Stimulating research seems indeed to be an appropriate way of action, insofar as it would probably seem delusive to take a more radical stance, given the economic stakes and the potential benefits. As Robinson puts it, under these conditions, the situation is less than ideal for the adoption of a strong version of the precautionary principle ([24], p. 12).

Moreover, in view of the considerable uncertainties associated with first generation nanotechnologies that are already on the market, both liability and moral responsibility attribution issues will arise in case of damage. Such issues will be difficult to solve considering the organised irresponsibility, which characterizes our late-modern risk society ([2]; [33], p. 18).

The Threat of ‘Nano-divide’

We have seen that equity issues were at stake with the development of nanomedicine and with human enhancement. However, equity and distributive justice issues emerge with generation 1. More specifically, the much talked about threat of nano-divide, which would increase the divide between North and South, is at stake. Nanotechnologies capable of improving quality of life as well as nanotechnologies considered purely as a factor of economic growth are at issue ([12], p. 29).

Indeed, several potential applications of nanotechnology could particularly benefit the developing countries ([1], p. 190–191). Water purification or solar energy production improved with the development of nanotechnologies are part of these applications. However, it is likely that developed countries will have access to these technologies, whereas developing countries who would particularly benefit from these technologies, will not be able to afford those. As Allhoff puts it ([1], p. 192), more generally, ‘there will be questions about whether we *can* use these technologies (given toxicity and other risks), whether we *have* to use these technologies (given obligation of environmental stewardship), and whether we have to *share* them (given obligations to international distributive justice)’. These questions appear to be already relevant for first generation nanotechnologies.

Moreover, in a globalised market, a possible geopolitical readjustment could result from an economy based on nanotechnologies. The development of nanotechnologies may possibly increase the economic gap between developed and developing countries, as nanotechnologies could replace raw material resources that need to be mined and that lie mainly in developing countries ([29], p. 224–225). For example, in electronics, carbon nanotubes could replace metal conductors that are made with gold or silver. Nanotechnologies could thus continue a trend in making industrialized countries independent of the resources of developing countries, thereby increasing the divide ([29], p. 225). However, emerging countries such as Brazil, South Africa, India or China have also launched their own R&D program in nanotechnologies—even though systematic patent protection and the associated licence fees make it particularly difficult for these countries to utilize the existing knowledge ([29], p. 224).

Nanotechnology as ‘Dual-use Technology’

Nanotechnology is a good example of ‘dual-use’ technology, as it is developed both for civilian and for military purposes, or—more broadly—as it has both beneficial/good and harmful/bad purposes, which includes the development of weapons ([30], p. 176).

Military secrecy makes it difficult to expand on ethical issues associated with the development of new military technologies. However, it is necessary at least to mention the existence of ethical problems, which concern all generations of nanotechnologies—it goes from toxic nanodust to enhanced battle-jumpsuits, autonomous weapons or biological weapons resulting from synthetic biology. Some kinds of applications appear to be beneficial only, such as nano-sized sensors that could help to detect chemical and biological weapons for example, whereas other applications could also contribute to create new threats that are precisely difficult to detect ([9], p. 228).

In fact, to some extent, the use of first generation nanotechnologies in the field of military applications—toxic nanodust for example—reiterates ethical issues already at stake with the development of nuclear and biochemical weapons such as the control and proliferation issues.

Moreover, the problems arising with the development of first generation nanotechnologies will only increase with later generations. For example, with human enhancement at the horizon, there will also be threats to the identity and the integrity of the soldier as a human being.

Conclusion

This paper has shown that fundamental ethical issues are at stake at each stage of nanotechnological development. Indeed, besides the particular ethical issues associated with generations 2, 3 and 4, crucial ethical questions arise already with the development of first generation nanotechnologies. These ethical issues are mainly associated with the social desirability of first generation nanotechnologies, with the difficulties to define nanotechnologies properly, with the consequences of the important uncertainties surrounding nanotechnologies, with the threat of ‘nano-divide’, and with nanotechnology as ‘dual-use technology’.

In fact, the cutting of the development of nanotechnologies into generations has an insidious effect: the ethical issues that are emphasized are inevitably

the ones associated with generations 2, 3, and 4 because these involve possibly direct intervention on the human being. Our attention is thereby diverted from ethical issues linked to first generation nanotechnologies, which are however currently being widely developed without proper ethical framing. The existence of issues associated with generations 2, 3 and 4 does not have to serve as a pretext to evacuate the ethical questioning related to generation 1.

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