Health Council of the Netherlands

Nanomaterials in waste

Gezondheidsraad
Health Council of the Netherlands

To the State Secretary of Infrastructure and the Environment

Subject : Submission of a horizon-scanning report *Nanomaterials in waste*
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Dear State Secretary,

I hereby submit the horizon-scanning report entitled *Nanomaterials in waste.* It was drafted by the Health and Environment Surveillance Committee, which is tasked with alerting the government and Parliament to important issues in the area of health and the environment, and with identifying any associated opportunities and threats. A draft version was assessed by the members of the Standing Committee on Health and Environment.

The horizon-scanning report highlights the increasing levels of nanomaterials in waste, in connection with possible risks to public health. This is not a new issue. It was cited in the 2006 Health Council advisory report entitled *Health significance of nanotechnologies.* It is already a focal point of government policy on nanotechnology. However, the Committee takes the view that the issue of nanomaterials in waste requires additional policy initiatives. In this horizon-scanning report the Committee explains its standpoint, and broadly identifies possible solutions.

I have sent copies to the Minister of Health, Welfare and Sport, the Minister of Economic Affairs, Agriculture and Innovation and the State Secretary of Social Affairs and Employment.

Kind regards,

(signed)
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to:

the State Secretary of Infrastructure and the Environment

No. 2011/14E, The Hague, July 26, 2011

The Health Council of the Netherlands, established in 1902, is an independent scientific advisory body. Its remit is "to advise the government and Parliament on the current level of knowledge with respect to public health issues and health (services) research..." (Section 22, Health Act).

The Health Council receives most requests for advice from the Ministers of Health, Welfare & Sport, Infrastructure & the Environment, Social Affairs & Employment, Economic Affairs, Agriculture & Innovation, and Education, Culture & Science. The Council can publish advisory reports on its own initiative. It usually does this in order to ask attention for developments or trends that are thought to be relevant to government policy.

Most Health Council reports are prepared by multidisciplinary committees of Dutch or, sometimes, foreign experts, appointed in a personal capacity. The reports are available to the public.

The Health Council of the Netherlands is a member of the European Science Advisory Network for Health (EuSANH), a network of science advisory bodies in Europe.

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The Health Council of the Netherlands is a member of the International Network of Agencies for Health Technology Assessment (INAHTA), an international collaboration of organisations engaged with health technology assessment.

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Contents

Executive summary

Nanotechnologies and nanomaterials are having a large and growing impact on society. For example, all kinds of nanomaterial-containing consumer products are being launched onto the market, including electronics and personal care products. In 2006, the Health Council of the Netherlands published an advisory report entitled “Health significance of nanotechnologies”, in which it called for a policy based on the precautionary principle. The Dutch government adopted this report’s recommendations in its 2006 Government Vision on Nanotechnology. Building on that previous advisory report, the Health Council is using this horizon-scanning report to raise awareness of the issue of nanomaterials in waste. It was drafted by the Health and Environment Surveillance Committee, which is tasked with alerting the authorities to important links between environmental factors and human health.

Costs and benefits of nanomaterials

Nanomaterials (which are just several millionths of a millimetre in size) have special chemical and physical properties: for example, some are highly efficient electrical conductors, while others are used to create water-repellent or dirt repellent coatings. These properties have spurred the use of nanomaterials in a range of product innovations in the consumer-, industrial-, and medical sectors. Some examples are sunlight-resistant paints; strong, lightweight plastics for the automotive and aircraft industries; and antibacterial coatings. Nanomaterials are also found in cosmetics, preservatives, cleaning agents, food packaging, and textiles.

However, relatively little is known about the risks to health associated with exposure to nanomaterials. Since the publication of the 2006 Health Council advisory report, there has been no substantial improvement in this situation. This is partly because the rapid rate of developments is outpacing our ability to identify any adverse effects that might be involved. One reason for this is the lack of routinely applicable methods for measuring the concentration of nanomaterials in various media. However, there is evidence to suggest that some nanomaterials are indeed harmful to health. Given the uncertainty surrounding the risks involved, it would be advisable to keep inadvertent human exposure to a minimum. This could include measures to ensure that, as far as possible, nanomaterials are prevented from entering the environment. Accordingly, waste management is an important consideration in this regard. Our waste already contains nanomaterials and, given the trends in development, production and use, the amounts involved will inevitably continue to grow.

Scope of the horizon-scanning report

This horizon-scanning report focuses on insoluble and non-degradable nanomaterials. It specifically addresses three components of waste management: recycling and incineration of solid waste, and wastewater purification.

The horizon-scanning report deals mainly with consumer products. However, its conclusions and recommendations apply to all nanomaterials that are potentially capable of releasing nanoparticles, and that are expected to be used in the near or longer term future. They also apply to all conceivable areas of application.

Recycling

The Dutch waste management sector places great emphasis on the separated collection and recycling of products and materials. It is not known what effect current materials recycling processes have on nanomaterials present in waste. Nor do we know the exact quantities involved.

Waste incineration

The remaining solid household waste, which is processed at waste incineration plants, contains an unknown amount of nanomaterials. The incineration of waste is always accompanied by the release of particles in the nanometre size range (referred to as ultrafine particles). Procedures to confirm the presence of various types of nanomaterials, and to measure their concentration, must target specific materials. This should be based on a combination of properties, including the numbers, surface area, and composition of the particles in question. However, that is not yet a viable option. There are no simple, reliable methods for measuring different types of nanoparticles in the air, nor for distinguishing them from one another and from ultrafine particles. Furthermore, it is not known how effective incineration plants are at removing nanomaterials from waste. However, there is evidence from scientific research that, aside from the ultrafine particles that are traditionally present, emissions from such plants also contain nanoparticles.

Water purification

Nanomaterials (from cosmetics and coatings, for example) can end up in waste water. Here too, no usable, specific techniques have been developed for routine analysis. The measurement problems associated with waste water are broadly the same as for air. Given the lack of appropriate measurement methods, it is not known how effective the waste water treatment process is at removing nanomaterials from water. As a result, there is a risk that they will enter the environment. Indeed, there is some evidence from scientific research to suggest that these materials are not completely removed.

There are also indications that nanoparticles can adversely affect the operation of wastewater treatment plants. Some consumer products, for example, contain nanoparticles with a bactericidal effect. These can impact the bacterial purification processes used at such plants.

Conclusions and recommendations

The Committee concludes that, when products are disposed of, little is known about the fate of any nanomaterials that they may contain. Similarly, it is not known how much of this material is present in waste, nor how much may be released into the environment. A growing body of scientific evidence indicates that nanomaterials may cause problems. Yet there are questions about the extent to which waste management is geared to the effective handling of such materials.

According to the Committee, there is every reason to scrutinise waste management and, in accordance with the precautionary principle, to focus on the presence of nanomaterials. It is advisable to start right away, before there is a steep climb in the amounts of nanomaterials in household waste and waste water. This is fully in keeping with waste management policy.

One of the implications of a proactive policy of this kind is that early on, at the product development stage, there should be a focus on the phase in which the product is discarded. The goal is to keep the amount of waste generated to a minimum. Our growing understanding of the harmful properties of certain nanoparticles must be integrated into the process of innovation. In this way, new generations of nanomaterials would have fewer adverse properties, or none at all. The government should encourage industry to adopt smart design and production techniques.

The producers, importers and users of nanomaterials have a responsibility to provide safe products, and should make every effort to do so safely. This could be achieved by exchanging know-how (and discussing their experiences) with experts from the waste sector when designing nanomaterials and products containing them. The waste sector can also get actively involved by modifying waste treatment processes where necessary and by considering how new waste treatment technologies might effectively contribute to the safe handling of nanomaterial-containing waste.

The Committee recommends that trends associated with future generations of nanomaterials and with the modernisation of waste management should be carefully monitored. Also, policy should be continually updated to reflect developments in these areas. Scenario analysis is a useful tool for identifying and quantifying nanomaterials in waste, and for pinpointing the waste streams involved.

The Committee recommends that funding be provided, as a matter of priority, to develop methods of measuring specific types of nanomaterials in media such as air and water. This was prompted by the fact that a lack of adequate measurement methods is one of the main reasons why risk management and risk research are lagging behind in the design, manufacture, and use of nanomaterials.

The Committee also feels that research is needed into the ways in which new waste treatment technologies can help tackle this issue.

Chapter 1

Introduction

1.1 Subject

In this horizon-scanning report, a Health Council committee examines the fate of a relatively new group of products (i.e. nanomaterial-based products) in the disposal phase. These products include electronics (and consumer electronics), packaging, personal care products and medical diagnostics.[1-4] This horizon-scanning report will show whether the fate of nanomaterials in products during the disposal phase is sufficiently well understood, and reveal the implications of this for public health.

1.2 Background

1.2.1 Nanomaterials and their applications

Nanoscience and nanotechnologies represent a broad field of study that has moved into the fast lane in recent years. The prefix “nano” is derived from the nanometre (nm), a unit of measurement equivalent to one billionth of a meter. The more finely divided a material becomes, the greater its surface area, while its volume remains the same. Materials with dimensions on the nanometre scale have quite different properties.

Nanomaterial-based products and nanotechnology applications include paints that are resistant to sunlight or that are self-repairing after damage, window glass with dirt-resistant coatings, and light and strong plastics (composites) for the automotive and aerospace industries, bactericidal coatings, and components of advanced technical equipment, plus all kinds of industrial processes (see Chapter 2).

1.2.2 *Unknown health risks*

Their special technical properties make nanomaterials so attractive that an ever wider range of products incorporating these materials are appearing on the market. These products are also being manufactured in ever increasing quantities. Besides opportunities, this also involves various risks, to public health, for example. A few years ago, the Health Council argued that, in the interests of public health, the precautionary principle be applied, and that the opportunities and risks be carefully weighed.[5] Regarding the health risks of using nanomaterials, the Council found that, while there are still many gaps in our knowledge, there is evidence that such risks do exist. For example, there is direct evidence that the inhalation of nanomaterials can result in health impairment. Thus, experimental animal studies with substances such as titanium dioxide and carbon black (soot, a form of carbon) in particulate form showed that exposure to these particles via the respiratory system can result in inflammation and tumours in the lungs. For each test substance, a given mass in the form of nanoparticles was shown to have a greater effect than the same mass in the form of larger particles.[6,7]

There is also significant indirect evidence that the inhalation of nanomaterials could be hazardous to health. This evidence was obtained in studies involving other small particles, known as fine particulates[*] and fibres.

Inhalation of fine particulates can cause disorders of the respiratory system, heart and blood vessels.[8,9] These effects are mainly attributed to the ultrafine fraction (particles with an aerodynamic diameter of less than 0.1 micrometers), i.e. that fraction with the dimensions of nanomaterials.[10,11]

The main fibres involved are various types that have been, or still are, used as insulation. These include glass fibres, glass wool, rock wool, slag wool, superfine glass fibres, ceramic fibres, *p*-aramid fibres, and asbestos. Some types have carcinogenic properties, others don't.[12-15] Even though these fibres have slightly larger dimensions than nanomaterials (micrometers), the carcinogenicity

* "Fine particulates" is a generic term for particles with an aerodynamic diameter of less than 10 microns which arise naturally (through soil erosion and volcanic eruptions, for example) or inadvertently as a result of human activity (for example, in processes such as the combustion of fossil fuels and the milling of substances in industry).

findings are relevant. Together with the results for nanomaterials and ultrafine particulates mentioned above, these findings suggest that nanomaterials may indeed exhibit hazardous properties, at least when inhaled. Nevertheless, the Council makes it quite clear that what goes for some nanomaterials does not necessarily apply to all materials in this category.

In addition to the Health Council, other institutions at home and abroad have highlighted the existence of health risks (e.g.[16-23]). Meanwhile, the amount of evidence has increased (e.g.[24,25] for review articles). Additional results from studies in cells, bacteria, and experimental animals show that some nanomaterials are capable of damaging genetic material, facilitating the creation of harmful substances (such as reactive oxygen species) or causing inflammation in the lungs. It appears that nanomaterials can also damage ecosystems.[26] This route could conceivably produce indirect effects on human health.

Over the past few years, there have been many new developments in Dutch policy on nanotechnologies. The main thrust of this work is to ensure that any decisions on the introduction of such technologies are taken with the greatest possible care. In 2006, the government submitted its Vision on Nanotechnology to the Lower House of the Dutch Parliament.[27] That document incorporated the Health Council's advisory report, and policy was formulated based on the precautionary principle. This policy was then further refined in the Nanotechnology Action Plan (for which the first progress report has now been published)[28-31.] The Action Plan also includes a measure to promote dialogue on the ethical and societal aspects of nanotechnology. The results were recently reported to the Lower House of the Dutch Parliament.[32,33] The Action Plan also includes steps aimed at the further analysis and curtailment of risks, such as further research into those properties of nanomaterials that are hazardous to health. The pace of development and the speed at which new products are being launched onto the market is so great that this study simply cannot keep pace.[34] Given the current level of technological development in our society, it appears to be fundamentally impossible for risk research to keep pace with applications research.[35] One practical problem is that the chemical-analytical methods used to check for the presence of conventional substances in humans, animals, and the environment cannot be used for nanomaterials. Another is that the development of suitable methods is a time consuming process.[36]

1.2.3 Waste

As part of the Action Plan, there will be a strong government and industry focus on the production and professional use of nanomaterials. Studies have now been carried out to determine how Dutch industry deals with nanomaterials.[37,38] Considerably less attention has been devoted to the phase in which these products are discarded. When drawing attention to the disposal phase, virtually all other sources also couch this in very general terms (e.g.[21,34]).

However, the increasing number of nanomaterial-based products will be reflected by increased amounts of nanomaterials in waste (even though this effect may not appear for some time).[39] Waste treatment could release insoluble and non-biodegradable nanomaterials into the environment, resulting in the inadvertent exposure of humans and the natural environment. If these materials possess hazardous properties then this could pose a real problem. Accordingly, until we know the extent to which the individual nanomaterials used possess hazardous properties, it is advisable to focus carefully on the disposal phase of those products that contain these materials, and on the release of such nanomaterials into the environment. A complicating factor in this regard is that we do not have comprehensive details about which products contain nanomaterials.

In this horizon-scanning report, the Health Council draws attention to issue of waste consisting of nanomaterial-based products. The goal is to prevent potential future health problems. The focus is on consumer products that contain insoluble and non-biodegradable nanomaterials. The Council is using this report to elaborate upon its recommendation (made in its previous advisory report on nanotechnology) that any risks should be identified at an early stage.

1.3 Question posed

This horizon-scanning report addresses the following two questions:

- To what extent are the waste disposal industry and its waste treatment technology equipped to deal with nanomaterial-based products?
- How does this affect the safe handling of nanomaterial-based products?

1.4 Committee and procedure

This horizon-scanning report was drawn up by the Health and Environment Surveillance Committee. Details of the make-up of the Committee are set out in Annex A.

In the context of preparing this report, the Committee paid working visits to the Rijnmond waste incineration plant (Van Gansewinkel Groep, Rotterdam), the DCMR Environmental Protection Agency (Schiedam), and the De Groote Lucht sewage treatment plant at Vlaardingen. The Committee also consulted various individuals with specific expertise in this area. Their names are listed in Annex A. During their interviews and working visits, the Committee obtained background information, familiarised themselves with the practical aspects of waste treatment, and tested their findings against the literature.

A draft version of this horizon-scanning report was assessed by the members of the Standing Committee on Health and Environment, one of the Health Council's permanent bodies of experts.

1.5 Structure of this horizon-scanning report

Chapter 2 gives a detailed description of nanomaterials and of how they are used. Next, in Chapter 3, the Committee examines the extent to which the waste treatment industry is equipped to deal with the processing of nanomaterials. In Chapter 4, it gives outline details of a waste policy based on the precautionary principle.

Chapter **2**

Use and life-cycle of nanomaterials

2.1 Definition, composition and form

In a previous Health Council advisory report, materials were classified as nanomaterials if they were smaller than 100 nm in at least one dimension.[5] As yet, there is no internationally accepted definition, although one is currently in the preparation stages (e.g.[40]). For the purposes of this horizon-scanning report, it is sufficient to state that these are materials consisting of particles of nanometre scale dimensions.

There are also materials that contain structures with nanometre-scale dimensions which are not particulate in nature. Such materials include computer chips (with nanogrooves), and filters (with nanopores) which can be used in water purification (removal of biological and chemical contaminants), for example. While this is unquestionably nanotechnology, these are not materials from which nanoparticles could be inadvertently released into the environment. Some take the view that the term “nanomaterials” should not be restricted to specially engineered materials alone. They feel that it should also include natural nanometre-scale materials (e.g. clay particles) that are deliberately added to products to change their properties. This issue is not dealt with in this horizon-scanning report.

Nanomaterials include organic or inorganic compounds, such as carbon, metals and metal oxides. They can also contain combinations of ingredients. Moreover, there are nanomaterials whose surfaces have been chemically altered. The latter group includes fullerenes (a molecular form of carbon) to which hydroxyl groups (or other functional groups) have been linked. Nanomaterials also occur in a wide variety of forms.[39] The particles may be spherical or spiral in shape, for example, and hollow or solid.

Nanomaterials can be processed in many different ways. They can be powders that are mixed with liquids (e.g. creams) to confer certain properties on the liquids in question (unbound nanomaterials). When mixed with a liquid that functions as a carrier (paint, wax, or spray, for example) they can be applied to surfaces as thin layers (bound nanomaterials). Nanomaterials can also be mixed with materials that undergo a hardening process. In this way, the nanomaterials contribute to the three dimensional structure of solids such as plastics (which are also bound nanomaterials). In the latter case, they are embedded in a matrix consisting of a different material. Where relevant, the terms "bound nano-particles" and "unbound nanoparticles" are used.

2.2 Products in which nanomaterials are used

Nanomaterials figure among the ingredients of all sorts of products that are either already on the market or which will be marketed in the foreseeable future. Their area of application covers the food sector, the consumer products sector, and the technology sector (including medical applications in medical treatment, medical diagnostics and health monitoring). Some applications were established long before it became trendy to use the term "nanotechnology". One example is carbon black, which makes tyres more resistant to abrasion. More recent applications of nanomaterials include food containers that keep food fresh for longer, and coatings that keep surfaces clean and free of bacteria. It was recently shown that a new type of coating with antibacterial properties is also effective against antibiotic-resistant microorganisms.[41] If this material is coated onto surfaces in hospitals with which staff come into contact, such as computer keyboards, this may well help to reduce the incidence of hospital-acquired infections. Other consumer products in which nanomaterials are used include paint, ink and toner, personal care products such as deodorants and cosmetics, clothing and furniture fabrics, and mobile phones. In the area of medical technology, they are used in wound care products and contrast agents for medical diagnostics.

In the area of consumer products alone, there are more than 1,300 nanomaterial-based products. These are manufactured by nearly 600 individual companies, located in 30 different countries.[1,2] For several years, government-backed studies have been identifying specific products, on sale in the Netherlands, that are suspected to contain nanomaterials.[3,42,43] The most recent data indicate that more than 850 nanomaterial-containing consumer products are available on the market.[4] These are mainly personal care products, cleaning agents, scouring agents, and clothing textiles. Nanomaterials are also used in the food chain, for such purposes as the production and processing of food, and in food packaging.[44] In some cases, powdered food products like coffee milk powder and instant soup contain silicon dioxide nanoparticles.[45] Other consumer products may also contain nanomaterials, without mentioning this in the product information.

2.3 Production and use of nanomaterials in the Netherlands

Nanomaterials are used in the Netherlands, but few are produced here.[37,38] Their industrial applications mainly involve the surface treatment and coatings sector. The substrates used here include textiles, metal, plastic, and glass. The lion's share of these materials are used in commercial applications. The top three (by weight) are carbon black, silica, and aluminium oxides.[38]

Other nanomaterials are used or produced in smaller (in some cases very much smaller) quantities. This mainly involves their development or use in commercial applications relating to products (including consumer products) which, generally, will not be available until some time in the future.

2.4 Life cycle of nanomaterial-based products

All products, whether or not they contain nanomaterials, pass through the stages of research and development, production, professional/non-professional use, and disposal. In some cases, a recycling stage is added at the end of the life cycle. This horizon-scanning report is based on waste treatment in the Netherlands.

Recycling is a cyclical process in which materials are wholly or partially reused for the same application (e.g. processing paper waste into new paper), or for a different, lower grade application (e.g. processing kitchen and garden waste into compost). Residual waste (the solid waste that remains after individual waste streams have been sorted/collected) generally undergoes no further separation and is incinerated. Only the non-combustible waste that emerges from this process is disposed of in landfill sites. Waste water is treated, and most of the sludge that emerges from this process is fermented (converted into gaseous products (mainly methane) under anaerobic conditions). Any residual material is then incinerated. In some cases, the sludge is composted.

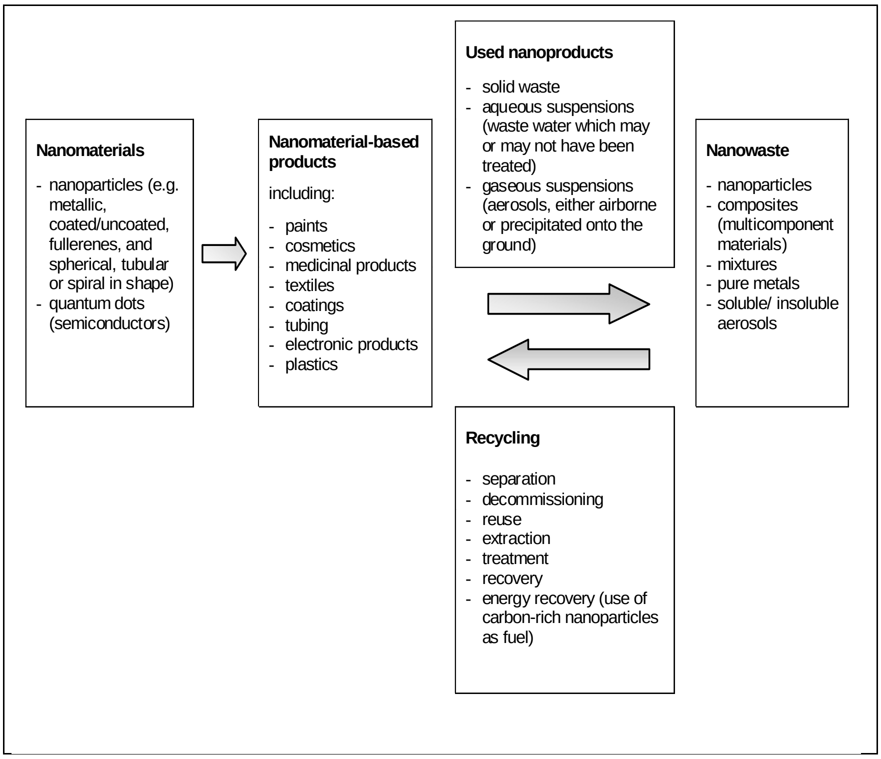

Figure 1 Diagram showing the life cycle of nanomaterials (from [39], amended)

Figure 1 is a diagrammatic representation of the life cycle of nanomaterials. Eventually, nanomaterial-based products arrive at the waste stage. The duration of the life cycle can vary widely from one product to another. For the packaging of perishable foods, this is a matter of weeks, whereas TVs or items of medical diagnostic equipment have life cycles measured in years.

There are also differences in how the waste is generated and where it ends up. For instance, after consumption, the plastic packaging of personal care products enters the solid waste stream and is then incinerated. This packaging often contains product residues. In such cases, waste can be created and can even enter the environment while the product is still in use. For instance, unbound nanoparticles can be released from personal care products that are applied to the skin, and disperse into the environment. Such particles can also be washed off under the tap, and when showering and swimming. They can then enter the waste-water stream.[46] Accordingly, the use and disposal phases cannot be strictly separated. Waste that may contain nanomaterials can also arise even earlier in the life cycle, during product manufacture, for example. This is the case with products such as disposable gloves and work clothing.

A collection system has been set up for electric and electronic appliances, as well as for batteries. The collected items are first dismantled, then any usable materials (metals and plastics) are recovered and reused. Any residual waste is incinerated. Inappropriately, items such as electrical products are sometimes discarded into domestic waste streams (generally small items like paint cans, mobile phones, and batteries). These objects are incinerated in their entirety, including any nanomaterials that might be present.

Accordingly, at various stages in the life cycle of nanomaterial-based products, individuals can unintentionally come into contact with the nanomaterials that they contain. This might involve members of the general public, for example, or just certain categories of employees (involved in the use of nanomaterials, or in the waste treatment sector). This varies from product to product. Nanomaterials can also create an environmental burden, not only in the disposal phase but also in the use phase, for example, by the inadvertent generation of waste. So there is a relationship between environmental exposure, and exposure of the general public and of employees. The details of this relationship vary, depending on which material, product, and application is involved.

As yet, little is known regarding the fate of nanomaterial constituents during the life cycles of nanomaterial-based products. Do they decompose, for example, do they react with other materials, or do they clump together (in the case of unbound particles)? In short, how do particles that have been incorporated into products emerge again at the end of the life cycle? How do the recovery and reuse of components affect any nanomaterials that are present? And how easy or difficult is it for a coating to shed its bound particles? To what extent can particles that are bound to components of the carrier or matrix be released from coatings and composites? What are the implications of this for the behaviour of nanomaterials in the product and in the media into which they may be released (e.g. outdoor air and waste water)? These are all relevant questions, but — as yet — there are no answers.

2.5 Anticipated developments

2.5.1 Near future

The Social and Economic Council of the Netherlands (SER) expects that there will be a sharp increase in the use of titanium and aluminium oxides in coatings, especially in new consumer products. In addition, numerous nanomaterials are being tested for many different applications (e.g. carbon nanotubes), or for use in composite materials (mixed with polymers) to make stronger plastics. Over time, these trends will probably result in the manufacture of a wide range of products based on these nanomaterials, and of many units of each type of product.

Other nanomaterials are being tested in knowledge institutions and, to a lesser extent, in companies for use in high-quality applications whose commercial viability is, as yet, uncertain. These include nanomaterials of gold, cerium oxide, or antimony oxide.

This preview does not cover all anticipated flows of materials and products. The import and export of nanomaterial-based products developed elsewhere in the world will almost certainly increase.

Expectations regarding the use of nanomaterials largely relate to those now being used as components or ingredients of existing types of products. Their main, shared characteristics are their passive, fixed structures and functions. These materials are referred to as the first generation of nanomaterials.[47]

The above description of the Dutch situation is also applicable, to some extent, to the second generation. The latter consists of active nanostructures that can change their properties (size, shape, or conductivity, for example) in response to a given stimulus. One example is nanoparticles used in the targeted delivery of medicinal products to tumours in the body and which, under the influence of a radiation source, release these drugs inside the tumour. Another, is the use of nanomaterials in molecular “motors” which provide motive power in response to light. Most of the products based on these types of nanomaterials are still under development, but it is not unrealistic to suggest that they could reach the market in the not too distant future.

2.5.2 In the longer term

More radical developments are in the offing over the longer term. There is much less certainty concerning their social impact, but this is likely to be profound.

There are currently indications that third and fourth generation nanomaterials are on the way.[47] The third generation involves systems of nanosystems, such as three-dimensional networks, biochemical and chemical assembly techniques, and nanoscale robotics. The fourth generation consists of molecular nanosystems which can be designed one particle at a time, e.g. for advanced genetic therapies. Self-organising nanoscale structures would also be considered part of this fourth generation. Indeed, it is even possible to describe the fifth generation in some detail.[48] This would include large, complex systems that are constructed from the nanoscale upwards.

Unlike the first two generations of nanomaterials, it will be much longer before the potential benefits of the third, fourth and fifth generations can be realised.

The changes are coming thick and fast. For instance, the number of consumer products in the Woodrow Wilson file (first generation) increased nearly six fold from 2006 to 2010.[2] The further developments are projected into the future, the less clarity there is concerning the social impact of these new technologies and materials (both beneficial and adverse). This also applies to the waste that they generate.

2.6 Conclusion

The nanotechnology/nanomaterials field is extremely dynamic. There will, in all probability, be a boom in the development and application of new generations of nanomaterials. To some extent, these issues challenge our imaginations, as does the associated disposal phase. In the wake of these developments, there will be an inevitable increase in the quantity and variety of nanomaterials in waste. Initially, this will involve first and second generation nanomaterials.

Chapter 3

Origin and treatment of nanomaterial-containing waste

This chapter assesses how well the waste disposal industry and its waste treatment technology are equipped to deal with nanomaterial-based products. The basic principle here is that the quantity of nanomaterials entering the environment should be restricted as much as possible.

Following a brief outline of the principles underpinning the general waste policy, the Committee discusses the origins and treatment of nanomaterial-containing waste. In this context, a distinction is drawn between products containing nanomaterials that are bound up in a matrix or to a carrier, and products that contain unbound nanoparticles. Three aspects of waste treatment are addressed: recycling, waste incineration, and wastewater treatment. The focus here is on first and second generation nanomaterial-containing consumer products. It covers the generation of waste during use, and when these products are discarded. The scope of the conclusions drawn has been extended to include future generations of nanomaterials.

3.1 Waste management

The Dutch policy on waste management aims to limit the amount of waste generated. The aim is to reduce the burden on the environment as much as possible, with corresponding knock-on benefits for people and animals. It covers the entire material chain, from production to waste treatment. The prioritisation of waste reduction involves reuse as secondary raw materials, or in other useful applications such as energy generation.

Waste management policy is enshrined in the 2009-2021 National Waste Management Plan, which is based on the Environmental Management Act.[49] This plan describes the Dutch waste management chain, which propounds the following order of preference: 1) prevention through waste prevention, 2) prevention by smart product design, 3) recovery through product reuse, 4) materials recovery (recycling), 5) recovery as fuel, 6) removal by incineration, 7) removal by dumping.

The earlier in the chain action is taken, the smaller the ultimate problem. After all, there is less residual waste to incinerate and to dump in landfill sites. Reusable glass bottles for beer and soft drinks are a familiar example of product reuse. In this case, materials recovery involves the manufacture of new glass objects from collected glass.

Aqueous waste is also covered by the Environmental Management Act, but not by the National Waste Management Plan, which is structurally unsuited to dealing with waste water issues. It has a distinct order of preference, one aspect of which is that first the creation of waste water and then the pollution of such water should be limited or prevented.

3.2 Bound-nanomaterial-containing products

3.2.1 Sorting, collection and reuse

The Dutch system involves the large-scale separation and separate collection of waste at source. The aim is to reduce risks to health from hazardous waste (e.g. asbestos) and domestic chemical waste (e.g. paint residues, energy-saving light bulbs, and medicinal products). In addition, sorting and separate collection facilitate the reuse of valuable products or components. In this way, the amount of residual waste is kept to a minimum. In waste-management parlance, materials recovery is referred to as recycling. A range of products and waste types are collected and processed separately. These include domestic kitchen and garden waste, plastic, paper, cardboard, batteries, discarded electrical and electronic equipment, as well as building and demolition waste.

Nanomaterial-containing waste

Various consumer products that are collected separately and recycled, such as batteries and electronics, already contain nanomaterials. Within the foreseeable future, the same will probably be true of many other products.

Accordingly, allowance must be made for the presence of nanomaterials when handling existing waste streams (and any new ones that may arise) from separately collected waste. To what extent does this require changes in waste management? Do innovations in the sorting, collection, and reuse of waste have the potential to curb the release of nanomaterials into the environment? As yet, we don't know.

3.2.2 Waste incineration

The regular combustible residual waste that is left after sorting and collection is either burned at waste incineration plants (WIPs; these are technical units solely or primarily intended for residual waste disposal by incineration, with energy recovery), or incinerated (with conventional fuels, such as gas and coal) in power stations. The incineration of residual waste is regulated by the Waste Incineration Decree.[50]

Residual waste includes residual domestic waste (residual waste from private households), comparable residual waste from businesses (residual waste from companies in the commercial, service, and government sectors) and sewage sludge, which is the residual waste from sewage treatment plants.

Presence of nanomaterials

It is likely that residual domestic waste already contains nanomaterials. We are aware that such waste includes the remains of consumer products, such as food and the packaging used for food and cleaning products. Such waste is indeed likely to contain nanomaterials, given the applications of these materials and the lifespans of the products into which they are incorporated. Regular domestic waste sent for incineration also includes unbound nanoparticles (tubes containing residues of nanomaterial-based creams, for example).

Other types of waste, generated by companies for example, may also contain nanomaterials. Various companies and knowledge institutions (universities and research institutes) who work with nanomaterials collect their own nanowaste.[37] Ultimately, however, this is disposed of with ordinary residual waste, as there are no facilities for separate collection.

Nothing is known about the quantities and types of nanomaterials that are currently present in our solid waste and residual waste. This applies to all of the waste streams cited here. This is mainly because the list of consumer products that contain nanomaterials is far from complete.

General effectiveness of WIPs

When residual waste is burned in a waste incineration plant (WIP), this produces flue gas, bottom ash (the ash that remains in the incinerator), and heat. The flue gas contains fly ash (solid combustion residues fine enough to be carried along in the flue gas stream) and water-soluble harmful substances, including acids. The flue gas is then scrubbed (in a series of washing and filtration steps) before emerging from the WIP's chimney. This process removes as many of the water-soluble and particulate (fly ash) contaminants as possible. The regulations state that the entire incineration process (including flue gas scrubbing) must use the best available techniques.[51] The bottom ash is processed into road-building materials (foundations and embankments), the fly ash is dumped.

The total process of incineration and flue gas scrubbing is designed to ensure that the concentrations of certain harmful substances created during the incineration process (including fine particulates) in the plant's emissions remain below set standards. The concentration of fine particulates in emissions is expressed as mass per unit volume of air. Studies have evaluated the effectiveness of flue gas scrubbing at WIPs, in terms of the removal of fine and ultrafine particulates. Emission measurements at WIPs before and after flue gas scrubbing show that, in quantitative terms, this process reduces the concentration of fine particulates by a factor of roughly one thousand. However, these measurements also showed that relatively high numbers of ultrafine particulates are not captured by scrubbing.[52-54]

Techniques for measuring nanoparticles in emissions

In terms of their size, nanomaterials that are not removed by flue gas scrubbing and which emerge from the chimney unchanged, are indistinguishable from ultrafine particulates. Accordingly, measurement methods based on different principles are needed to detect and quantify these materials. The problem is that there are no specific and reliable methods for detecting and quantifying specific nanomaterials (or groups of nanomaterials).

Quantitative measurements alone are not sufficiently characteristic. Measures suitable for quantifying nanomaterials in air involve a combination of variables, such as the number of particles, as well as the material's surface area and composition. However, the measurement of these characteristics is still subject to considerable scientific debate. Currently available equipment is capable of measuring the particles contained in an air sample, in terms of particle size distribution and numbers per size class. However, it is much harder to measure the composition of individual particles and of particles within those classes. Accordingly, it is no easy matter to monitor emissions from WIPs for the presence of specific nanomaterials (or groups of nanomaterials) and to determine how effectively these are removed in the process of waste incineration. As yet, there are no practical techniques for the routine analysis of air samples. More detailed evaluations of measurement methods can be found in review articles and supplementary publications (e.g.[55-57]). To date, it has only been possible to collect data through the use of time-consuming experimental techniques.

Incomplete removal of nanometre-scale materials

Partly due to the lack of reliable, routinely applicable methods for measuring specific types of nanoparticles in air, it is not known how effectively waste incineration plants remove the nanomaterials that are present in residual waste. While some publications do address the issue of waste incineration and nanomaterials, they do not explore the fate of materials in residual waste that is sent for incineration. For instance, while one such publication involved an analysis of fly ash, it is possible that the nanometre-scale carbonaceous particles detected (which included fullerenes) were formed during the process of incineration itself.[58] Such particles are known to form during the combustion of carbon.[59] Accordingly, the analysis of fly ash cannot show whether or not nanomaterials in waste sent for incineration are removed during this process.

What can be deduced from studies into the effectiveness of flue gas scrubbing is that it does not remove all ultrafine particulates. However, so little of this material escapes that the contribution of WIP emissions to the concentration of ultrafine particulates in outdoor air is dwarfed by that of traffic emissions.[52] If nanomaterials, too, are allowed to escape, even if only in small quantities, this could be a problem (depending on their harmfulness).

The few findings mentioned above, which were obtained using time-consuming (i.e. not routinely applicable) analysis methods, support the view that emissions from waste incineration plants include small particles other than those created de novo during the incineration process itself. In addition, many other issues are still unresolved. For example, we do not know if it matters whether the nanomaterials are unbound, or whether they are fixed onto or inside another material (or, indeed, whether the nature of that other material has a part to play). Also, could the size of the waste fragments sent for incineration be in any way significant? Similarly, we do not know whether the special properties of the nanomaterials themselves affect the process of incineration, or whether their combustion differs in any way from that of corresponding non-nanomaterials. Nor do we know whether nanomaterials undergo chemical and physical changes during incineration. In theory, all of the carbon in carbon-based nanomaterials will undergo combustion. However, this is dependent on the conditions (such as the temperature) and the size of the waste fragments in question. Other materials, such as precious metals and metal oxides, do not burn but can undergo chemical and physical interactions with other inorganic constituents of waste.

New waste disposal processes

New, environmentally friendly waste disposal technologies are being developed and introduced. These include gasification, which is an alternative to incineration. Gasification is a chemical process in which materials are converted at high temperature into a mixture consisting mainly of hydrogen and carbon monoxide. The former is a gaseous fuel that can serve as an alternative to natural gas. Even assuming that they would be economically feasible in practice, it is important to ask whether these technologies represent a genuine advance in terms of the removal of any nanomaterials present in waste.

3.3 Unbound-nanomaterial-containing products

Waste water may contain particles (including unbound nanoparticles). Waste water is treated in a sewage treatment plant or wastewater treatment plant. These are technical units to which water is transported through the sewers. Here, it is treated to the point at which it is permissible for it to be discharged into surface water. The water entering such units consists of domestic waste water combined with industrial waste water of comparable quality (in terms of the biodegradability of any contaminants that are present). While the principles of wastewater treatment are common to all treatment plants, some may use different techniques at various stages of the process. Broadly speaking, this involves aeration, bacterial decomposition, and the removal of particles by sedimentation. There are requirements, in the form of maximum permissible concentrations for certain substances (such as phosphates, nitrogen, and undissolved particles) in purified waste water.

Waste water entering the plant contains small particles (which are insoluble and non-biodegradable) of the same dimensions as nanoparticles. These include dust from the streets that is carried into the drains in rainwater runoff.

Introduction of nanoparticles

Many types of products containing unbound nanoparticles suspended in liquids can give rise to nanoparticle-containing waste water. The nanoparticles used in cosmetics are ultimately washed off the skin into water streams that are carried away in the drains. Water from showers, sinks, toilets and rain enters the drains, which divert it into sewage treatment plants.

Incidentally, it is worth noting that products containing bound particles can also release nanoparticles into waste water. Wear and tear can cause nanomaterials bound into a three-dimensional matrix to be released. However, this is seldom likely to occur under normal circumstances. With regard to coatings, the quality of the bond will determine both the extent to which nanomaterials are unintentionally emitted into the environment, and the route that they take. However, there are situations in which a layer of nanomaterial may shed unbound nanoparticles, e.g. when paint is sanded. Rain (outdoors) or cleaning activity (indoors) can then flush the resultant dust into the drains. It has been shown that nanoparticles are indeed emitted by coatings. For example, nanoparticles of titanium dioxide have been detected in water running down outside walls coated with paint containing this substance.[60]

Moreover, there is evidence that nanoparticles are indeed present in waste water. In an area of the U.S. where silver is unlikely to occur naturally, nanometre-scale silver sulphide particles have been detected in sewage sludge.[61]

Incomplete removal of nanoparticles

Given the findings of the U.S. study cited above, it is plausible that silver-containing nanoparticles may be present in waste water. The same study shows that it may also be possible to remove them from this medium.[61] After all, they have been found in sludge. It seems that silver nanoparticles precipitate as insoluble silver sulphide. However, the study gives no indication of how much silver is removed from waste water in this way, as the concentration of this element in water entering the treatment plant was not measured.

Another study shows that various types of nanoparticles are partially removed with the sludge under laboratory conditions that mimic the operation of a sewage treatment plant.[62,63] These tests involved nanoparticles of cerium oxide and titanium dioxide, plus various types of nanoparticles based on silver and carbon.

Although the picture is far from complete, there is at least some evidence to suggest that nanoparticles are not completely removed by wastewater treatment.

The sedimentation study of particles in general also sheds light onto the anticipated sedimentation behaviour of nanoparticles. Sewage treatment plants can remove particles with diameters of 1 micron or more from waste water by sedimentation.[46] At this scale we also find aggregates of smaller particles, some of which may be bound to other sludge constituents. Nanoparticles that behave in this way will also be removed from waste water by sedimentation. Those that are not will still be present in treated water. It is not known to what extent sedimentation contributes to the removal of nanomaterials. However, laboratory research into the behaviour of nanomaterials in aqueous fluids carried out for the purpose of designing tests to determine the potential harmfulness of nanoparticles has generated results that could provide a useful stepping stone.[64-66]

Effect of nanoparticles on the operation of sewage treatment plants

There are also indications that nanoparticles present in waste water can adversely affect the operation of sewage treatment plants. For instance, under laboratory conditions, silver-containing nanoparticles can affect the bacterial treatment process.[67] Theoretically, nanoparticles pose a plausible threat to this step in the wastewater treatment process. This is because the nanoparticles used in the study belong to a type that was deliberately designed to kill bacteria. These very bactericidal properties are the reason that these particles are being incorporated into a wide range of products (including consumer products). The best known example is silver-containing nanoparticles in a range of products, including socks and coatings for lavatory bowls and washing machines. The silver ions released by these nanoparticles are responsible for their antibacterial activity.

Accordingly, there are experimental findings and theoretical considerations to support the view that nanoparticles with antimicrobial properties may be a threat to mainstream wastewater treatment processes.

Any threat to wastewater treatment poses a clear and indirect hazard to human health. This is, therefore, a more specific risk than that posed by the incomplete removal of nanoparticles, whose potential impact on human health is much less clear.

Measuring nanoparticles in water

Methods for measuring specific types of nanoparticles in waste water (before and after treatment) are still in their infancy. Broadly speaking, the issues here are the same as those involved in the analysis of air. The methods that are conventionally used to measure substances in water are based on mass and composition. As a result, no practical techniques are yet available for the routine testing of water samples for the presence of nanoparticles. Given this lack of routine tests, the scientific studies cited above involved the use of time-consuming analytical methods such as electron microscopy. More detailed evaluations can be found in various review articles (e.g.[55,56,58-70]).

New waste disposal processes

Wastewater treatment is being continually improved and made more environmentally friendly, by cutting the consumption of chemicals and energy, for example.[71] As with waste incineration, there is little understanding of how new technologies could be harnessed to remove nanoparticles.

3.4 Conclusion

Firstly, the Committee concludes that, when products are discarded, we still have only a limited understanding of the fate of the various nanomaterials that they may contain. Similarly, it is not known how much of this material is present in waste, nor how much may be released into the environment. This is the case in all three waste treatment methods considered here: recycling, waste incineration, and wastewater treatment. It applies not only to the current situation but also to the impact of any future changes in waste treatment technologies and in the composition of waste streams (resulting from the separate collection of additional types of waste). An additional issue is that it is impossible to draw a clear distinction between the use phase and the disposal phase. There are two main reasons why the fate of nanomaterials in waste is so poorly understood. Firstly, this issue is not currently a priority and secondly there is a lack of suitable analytical methods. Another consideration is that there may be nanomaterial-containing products on the market which are not identified as such. As a result, we cannot be sure which waste streams will ultimately contain these nano-materials.

The creation of nanowaste lags behind the production and professional use of nanomaterials. To a lesser extent, the same is true with regard to the ultimate products (and consumer products). This trend appears to be mirrored by people's interest in, and knowledge of, the risks associated with the various life stages of nanomaterial-based products, with the waste stage bringing up the rear. The Committee has the impression that the government and the waste treatment industry still do not fully appreciate that we are on the verge of a growth in the quantity and variety of nanomaterials in waste.

There is only a limited range of options for measuring the levels of nanomaterials in emissions from waste incineration plants and treated waste water. To date, it has not been possible to make reliable routine measurements in air and water. As a result, we do not know whether waste incineration and wastewater treatment are emitting modified or unmodified nanoparticles into the environment.

The Committee concludes that it is not clear whether waste management practices are sufficiently well attuned to the presence of nanomaterials, or to the anticipated short term and long term changes in the quantity and nature of those materials. Various trends in the scientific literature indicate that this situation needs to be remedied. Based on a limited body of evidence, it is quite plausible that nanoparticles are released in the process of waste incineration. In the case of wastewater treatment, there is indirect evidence that nanoparticles are being discharged into surface water. Furthermore, in its present form, wastewater treatment is potentially at risk from waste water containing nanoparticles with antimicrobial activity.

Accordingly, the Committee concludes that there are indications that current waste treatment practices are not sufficient to prevent nanomaterials from entering the environment, and that the wastewater treatment process may be at risk. However, the development and introduction of new waste treatment processes provides opportunities for a greater focus on to the fate of nanomaterials in waste.

Chapter **4**

Repercussions for the safe handling of nanomaterial-based products

In this chapter, the Committee addresses the implications of its findings for the safe handling of nanomaterial-based products and, more generally, developments in the field of nanomaterials, to avoid adverse health effects as far as possible.

4.1 Precautions

Our understanding of exposure to various nanomaterials and of these materials' potential harmfulness to human health is patchy at best. This underscores the need to act in accordance with the precautionary principle. An earlier Health Council advisory report defined precautionary action as dealing with uncertainties carefully and in a way that is tailored to the issue at hand.[72] This means that, when assessing the problem and formulating policy decisions, the pros and cons of possible courses of action, the associated uncertainty, and the implications for stakeholders are identified and weighed against one another. In the nanomaterials issue, it is important to examine the entire life cycle of nanomaterial-based products in great detail, to protect the environment, the general public, and employees. It is a good idea to give greater consideration to the issue of waste generation, as little is known about the quantity of nano-materials released into the environment at this point. In line with the pre-cautionary principle, the Dutch government has already set policies in motion that allow for the presence of nanomaterials in waste, before there is any significant increase in the concentrations of nanomaterials in various waste streams. Such policies are fully in keeping with the principle of sustainable waste management, as set out in the 2009-2021 National Waste Management Plan.[49]

The following sections offer points of reference for such policies.

4.2 Twin-track approach

The twin-track approach on which mainstream waste management is based is equally applicable to the management of nanomaterial-containing waste. This approach involves waste prevention and the safe handling of waste.

Nanomaterials must be prevented from entering waste streams, as a matter of priority. As with non-nanomaterials, the motto here is “the earlier in the material chain you intervene (from production to disposal) the greater the beneficial effect.” This applies to all nanomaterials, whether in bound and unbound form. Smart (or smarter) design and smarter production methods can play an important part in this. The government has been fostering this approach for quite some time. At international level, this gained extra prominence when the concept of Cradle to Cradle (C2C) was launched. This embodies the ideals of recycling and of eliminating residual waste.[73] Products should be designed such that, once they have been used, all of their component materials are either available for high quality reuse (by being incorporated into a new product) or are returned to a biological cycle (the natural decomposition of wood, for example). With nanomaterials and nanomaterial-based products, smart design and manufacturing can help to ensure that, at the waste stage, little or no such material is released into the environment. The available options will have to be reviewed on a case by case basis.

In addition to taking preventive measures, it is advisable to invest in the safe (or safer) removal of any nanowaste that may slip through this net. This could involve a careful examination of the processes of recycling, waste incineration, and wastewater treatment, and modifying them where possible. Harnessing new technologies for the treatment of solid waste and waste water could be fruitful in this regard. One example is the aforementioned process of gasification, which could be used to treat specific types of solid waste.* Further research is needed to clarify the impact of gasification and other new technologies on the fate of any nanomaterials present in waste.

* The Energy research Centre of the Netherlands, at Petten, and the HVC energy and waste utility, at Alkmaar, are working on a joint pilot project for the gasification of scrap wood, a residual waste stream that can contain nanomaterials (paints, coatings).

4.3 Awareness and communication

There is great uncertainty concerning the health risks associated with nanowaste, as these are still very difficult to assess. In terms of the evaluation and decision-making process, this involves continuing the existing public dialogue.[32,33] Two groups deserve special attention in this regard, one consists of the government and industry, the other is the general public.

4.3.1 Government and industry

From a precautionary standpoint, it makes sense to alert the numerous stakeholders (including the government, manufacturers, importers and the waste treatment sector) to the anticipated growth in nanowaste (both in terms of quantity and diversity). They should also be made aware that a proactive policy is needed, as we lack sufficient knowledge to accurately determine the risks posed to public health by nanowaste. In the Committee's view, government and industry must act in unison to resolve this issue. This involves the waste treatment operators, as well as actors with responsibility for other parts of the material chain, such as the manufacturers and users of nanomaterials.

The waste treatment operators can also get actively involved by using their knowledge and experience to modify waste treatment processes where necessary. They can also consider how new waste treatment technologies might effectively contribute to the safe handling of nanomaterial-containing waste.

The manufacturers, importers and users of nanomaterials must play an active part in preventing the generation of nanowaste. After all, under existing legislation in the field of environmental and consumer protection, they do have a duty of care. Indeed, the Environmental Management Act stipulates a general duty of care for the environment. Furthermore, the EU "REACH" (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation stipulates a duty of care when handling substances. The latter requirement means that companies have a responsibility to take action when they suspect that a substance that they produce, market or use can cause harm to individuals or to the environment. This involves any measures that might reasonably be expected to be taken to eliminate such hazards, or to reduce them as much as possible. Industry could meet this requirement (which also covers the waste treatment sector) by arranging for the designers of nanomaterials and nanomaterial-based products to discuss technical details and practical know-how with experts from the waste sector.

4.3.2 General public

The Committee also feels it advisable to reach a well considered decision on how best to inform and involve members of the general public. This is important in terms of boosting support for policy innovation (e.g. the separate collection of more types of waste).

In some cases it may also be useful to make clear to the public that they can avoid inadvertent exposure to nanomaterials by taking safety precautions when handling products that contain such materials, right up to the moment that they are discarded. The Committee feels that the need for such precautions should be considered on a case by case basis. This only makes sense where there is a specific problem. In such cases, instructions can be issued on what to do, or what not to do. Messages about nanomaterial-based products and their waste that are couched in broad terms are only appropriate where they are indeed generally valid.

This means that careful consideration should be given to the communication in question well in advance. Such messages must be issued proactively, and they must deal with all aspects of use, rather than focusing on waste alone. Points of reference can be found in the results of social dialogue to date.[32,33]

The existing Risks of Nanotechnology Knowledge and Information Centre (KIR nano) could play a part in making information on the issue of nanowaste accessible to the general public.

4.4 Points to note for nanowaste policy

The Committee feels that additional policy is needed for dealing with any nanowaste that has been generated. This applies to all three waste treatment methods considered here: recycling, waste incineration, and wastewater treatment.

The policy must allow for, and anticipate, rapid developments in nanotechnology and trends in waste management. These include the following:

- Diversity of nanomaterials. Nanomaterials are a heterogeneous group in terms of both their chemical and physical properties, and with regard to their applications. As a result of this heterogeneity, different types can be expected to occur in different waste streams. The procedural implications are not immediately clear. For example, would a group-based approach to materials or products be useful and workable? A single, broad approach might not suffice.

- Trends in the field of nanotechnology. The field of nanotechnology is extremely dynamic. There is a continuous influx of new nanomaterials. Incidentally, some nanomaterials can contribute to sustainable waste treatment, particularly in the production of drinking water.[46] The Committee's analysis focuses mainly on what are known as first and second generation nanomaterials. This is largely motivated by the fact that the limited amount of waste-issue-related information available concerns these generations. In the Committee's view, however, the policy to be formulated should look further ahead, taking into account future generations of nanomaterials.
- Trends in the field of waste management. Waste management, too, is in a state of flux. In addition to organisational changes (privatisation), substantive changes are taking place, to make processes more sustainable, for example. In this connection, a related goal might be to cut energy consumption.[49-51,71] One aspect of this involves the development of new technologies, such as the above-mentioned gasification of waste. Another consideration is that waste streams are not fixed. They can vary from time to time, as a result of policy changes. For instance, the separate collection of plastics creates a separate waste stream. This reduces the amount of residual waste left behind, and changes its composition. Accordingly, future-proof waste management for nanomaterials has two important features. It is proactive in relation to technological developments in waste treatment and discounts the interdependence of waste streams.

4.5 Specific approach

4.5.1 Monitoring

When creating an adequate waste policy that anticipates trends in nanotechnology and waste treatment, it is important to identify current nanomaterial-containing waste flows, in addition to those that we will have to face in the near and distant future. Scenario analysis could be a useful tool for identifying and quantifying nanomaterials in waste, and for pinpointing the waste streams involved.

The requisite key elements are a workable, internationally observed definition of nanomaterials, and measurement methods capable of conveying a more accurate impression of the quantities of nanomaterials released during waste treatment. In this context, it makes sense to push for a link between the emergence of new nanomaterial-based products and the availability of new analytical methods capable of determining the concentrations of the nanomaterials in question in the environment.

4.5.2 *Sticking points*

The Structural Assessment of Environmental Law, Nanotechnology Component (STEM nano) was recently carried out. This allowed the government to explore the available options for implementing policy on nanotechnology and nanomaterials.[74] STEM nano identified a wide range of potential policy tools, such as the establishment of a notification requirement for the manufacture and use of nanomaterials. Other such tools are admission requirements for nanomaterials, separate collection and recycling of discarded nanomaterial-based products, treating nanomaterial-based waste as potentially hazardous, and the above-mentioned duty of care.

STEM nano notes that EU and Dutch legislation involves sticking points that hinder the application of such policy tools to nanomaterials. This legislation appears to be insufficiently focused on the special properties of nanomaterials. The government wants action to be taken at EU level to accelerate the procedural steps needed to eliminate these and other sticking points in European legislation.[75] Waste management definitely merits inclusion in the planned risk assessment system for nanomaterials.

The Committee recommends that consideration be given to encouraging manufacturers to adopt smart design and production techniques. In this way, as much waste as possible would be recycled for high quality reuse, thereby minimising the amount of residual waste generated. It also recommends that industry be encouraged to take this one step further, by harnessing the insight that it has gained into the properties and behaviour of specific nanomaterials for the development of subsequent generations of nanomaterials. This would involve the deliberate channelling of developments in directions that would pose the minimum possible risk to health.

4.5.3 *Research*

The Committee proposes that research in the following two areas be actively encouraged:

- Research into new waste treatment technologies and their potential use in curbing the quantities of nanomaterials released into the environment via waste.

- The development of reliable, specific methods for measuring individual types of nanomaterial (or groups of nanomaterials) in given media (air and aqueous liquids). Such methods are needed to test for the presence of nanomaterials in waste, and for assessing how well waste incineration plants and sewage treatment plants prevent the release of nanomaterials into the environment. Measurement methods are also a prerequisite for formulating possible standards (emission requirements) for facilities such as waste incineration plants and sewage treatment plants. Methods for measuring specific nanomaterials (or groups of nanomaterials) are also needed to make exposure estimates, and to identify the health risks associated with exposure to nanomaterials in general, and those found in waste in particular.

4.6 Conclusion

The field of nanotechnologies and nanomaterials is evolving rapidly, but it will take time for the various developments to crystallise out. Some of these issues challenge our imagination, as does the associated disposal phase. Waste management should be modified accordingly. This requires policy that is both proactive and able to reflect the dynamic nature of these developments. This view is in keeping with standard waste policy. If waste management is to be made future-proof then it must provide for coherence between the two pillars of waste management (the prevention of nanowaste and the safe handling of any nanowaste that is generated) and the trends in waste treatment and in nanomaterials. It must also allow for a customised approach to different nanomaterials (and groups of nanomaterials).

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A The Committee

Annex

Annex **A**

The Committee

The Health and Environment Surveillance Committee has the task of bringing subjects concerning health and the environment to the attention of the government and Parliament, and of highlighting threats and opportunities. This may be in relation to new issues but may equally concern topics that require attention once again.

Members of the Committee charged with the preparation of the present advisory report:

- Professor W.F. Passchier, *chairman*
  Emeritus Professor of Risk Analysis, Maastricht University
- Professor M. van den Berg
  Professor of Toxicology, Institute for Risk Assessment Sciences, Utrecht University
- Professor J.W. Erisman
  Professor of Integrated Nitrogen Issues, VU University, Amsterdam, and Unit Manager of Biomass, Coal & Environmental Research, Energy Research Centre of the Netherlands, Petten
- P.J. van den Hazel
  Physician, Specialist in Environmental Medicine, Public Health Service Central Gelderland, Arnhem

- Professor R. Leemans
  Professor of Environmental Systems Analysis, Wageningen University and Research Centre
- Professor E. Lebret
  Professor of Environmental Health Impact Assessment, Institute for Risk Assessment Sciences, Utrecht University
- Dr. A.J.A.M. Sips, *advisor*
  Toxicologist, Specialist in Pharmacokinetics and Toxicokinetics, National Institute for Public Health and the Environment, Bilthoven
- Dr. J.P. van der Sluijs
  Researcher in Science, Technology and Society, Copernicus Institute for Sustainable Development and Innovation, Utrecht University
- Professor D.R.M. Timmermans
  Professor of Risk Communication and Patient Decision Making, EMGO Institute, VU University Medical Centre, Amsterdam
- Dr. P.W. van Vliet, *scientific secretary*
  Health Council of the Netherlands, The Hague

When drawing up this advisory report, the Committee consulted various individuals with specific expertise in this area.

The following persons were consulted:

- Professor P.J.A. Borm
  Professor of Toxicology, Heinrich Heine University, Düsseldorf, Germany; CEO Magnamedics Diagnostics bv, Geleen
- Dr. M.K. Cieplik
  Environmental Chemistry Expert, Energy Research Centre of the Netherlands, Petten
- Dr. P.C. Rem
  Associate Professor of Raw Materials Processing, Delft University of Technology
- Professor A. Schmidt-Ott
  Professor of Particles Technology, Delft University of Technology
- Dr. B.G. Temmink
  Environmental Technology Expert, Wageningen University and Research Centre

The Health Council and interests

Members of Health Council Committees are appointed in a personal capacity because of their special expertise in the matters to be addressed. Nonetheless, it is precisely because of this expertise that they may also have interests. This in itself does not necessarily present an obstacle for membership of a Health Council Committee. Transparency regarding possible conflicts of interest is nonetheless important, both for the chairperson and members of a Committee and for the President of the Health Council. On being invited to join a Committee, members are asked to submit a form detailing the functions they hold and any other material and immaterial interests which could be relevant for the Committee's work. It is the responsibility of the President of the Health Council to assess whether the interests indicated constitute grounds for non-appointment. An advisorship will then sometimes make it possible to exploit the expertise of the specialist involved. During the inaugural meeting the declarations issued are discussed, so that all members of the Committee are aware of each other's possible interests.