Regulating nanoparticles: A complex balancing act

Sylvia Isabelle Sarah Dean
BA (Hons), MA, MSc

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Durham University
Durham Law School
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Abstract

Regulation is a key part of product commercialisation, where different stakeholders must continually negotiate what are often conflicting regulatory drivers. High technology regulation is particularly problematic as is found in nanotechnology, and nanoparticle products, where there is much misunderstanding about what these products are and how they work. Nanotechnology is the application of small products, ranging between one hundred million and one billion times smaller than a metre, considered as the next 'industrial revolution'. At the vanguard of nanotechnology products, nanoparticles are examined in this study, where rapid technological advances are creating much debate within the discipline of law for how to best regulate the nuanced physicality of these products. Extant arguments have focused on how to regulate the R&D, production, sale, consumption and end-of-life of these products, with varying considerations of physicality which is pivotal to this endeavour. Critically, and fundamental to any discussion about regulating nanotechnology is whether these products sit inside of current regulations, or whether they require new regulatory approaches to more adequately capture their physicality. Confusingly, there has often been an erroneous presupposition that nanotechnology will function as a direct mirror of larger products, which is often not the case. On this basis, this study engages with the physicality of nanoparticles to build a foundation of knowledge, asking pivotal questions about regulation, to better inform academic and industrial regulatory discourses. Attention is given to regulatory frameworks including the Precautionary Principle, Regulation, Evaluation, Authorisation and Restriction of CHemicals (REACH), and potential for nanotechnology registries for monitoring nanoparticle physicality. Importantly, for any collection of highly nuanced novel physical products as found within nanotechnology, there can be no 'one-size-fits-all', with in depth examinations being made with different specific sectors to draw out the major challenges related to the physicality of this wide ranging collection of products.

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Abbreviations

ANDA	Abbreviated New Drug Application
ANSES	Agency for Food Safety, Environment and Labour (France)
ASTM	American Society for Testing and Materials
B2B	Business-to-Business
B2C	Business-to-Consumer
BGH	Bovine Growth Hormone
BSE	Bovine Spongiform Encephalopathy
BSI	British Standards Institute
CGL	Commercial General Liability
CHMP	Committee on Medicinal Products for Human Use
CLP	Classification, Labelling and Packaging
CNT	Carbon Nanotube
COSHH	Control of Substances Hazardous to Health
CPI	Centre for Process Innovation
DSEAR	Dangerous Substances and Explosive Atmospheric Regulations
ECETOC	European Centre for Ecotoxicology and Toxicology of Chemicals
ECHA	European Chemical Agency
EFSA	European Food Safety Authority
EINECS	Existing Commercial Chemical Substances
EMS	Environmental Management Systems
ENI	Environmental Nanoscience Initiative (UK)
ENPRA	Risk Assessment of Engineered Nanoparticles
EPA	Environmental Protection Agency
EPSRC	Engineering Physical Sciences Research Council
ETUC	European Trade Union Confederation
EU	European Union
FDA	Federal Drug Administration
FP7	Framework Programme 7
HSE	Health Safety and the Environment

IOM	Institute of Medicine
IP	Intellectual Property
IPR	Intellectual Property Rights
IRGC	International Risk Governance Council
ISO	International Organisation for Standardisation
LENS	Lake Ecosystem Nanosilver
MA	Marketing Authorisation
MHRA	Medicines and Healthcare Products Regulatory Agency (UK)
MIAN	Minimal Information about Nanomaterials
MM	Micrometre
N&ETWG	New & Emerging Technologies Group
NERC	Natural Environment Research Council
NIA	National Industries Association
NIH	National Institute of Health
NIOSH	National Institute for Occupational Safety and Health
NM	Nanometre
NONS	Notification of New Substances
OED	Oxford English Dictionary
PPE	Personal Protective Equipment
PtD	Prevention Through Design
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of CHemicals
ROI	Return-on-Investment
RSC	Royal Society of Chemistry
SCCP	Scientific Committee for Consumer Products
SCCS	Scientific Committee on Consumer Safety
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SDS	Safety Data Sheets
SME	Small to Medium Enterprise
SPF	Sun Protection Factor

SWCNT	Single Walled Carbon Nanotube
UK	United Kingdom
UNESCO	United Nations Educational Scientific and Cultural Organisation
UNFAO	United Nations Food and Agricultural Agency
US	United States (of America)
USA	United States of America
USDA	United States Department of Agriculture
UV	Ultra Violet (light/radiation)
UVA	Ultra Violet (light/radiation) A
UVB	Ultra Violet (light/radiation) B
WEL	Workplace Exposure Limit
WHO	World Health Organization
WP	Web Page – used in citing references where no page number is given on document
WPMN	Working Party on Manufactured Nanomaterials

Glossary

Antimicrobial:	A chemical solution used to kill microorganisms, potentially including bacteria, yeast, fungi and viruses (Dana, 2012).
Asbestos:	Naturally occurring silicate materials that have been heavily used in construction but have been found to be highly toxic (Alleman and Mossman, 1997).
Bulk:	Macroscale phenomena which can typically be viewed without the aid of a microscope (Dana, 2012).
Construction:	The use of discourse to convey a view or perception of reality (Wood and Kroger, 2000).
Dermis:	The layer of skin between the most outer layer contacting the 'outside world' (epidermis) and subcutaneous (inside) tissue (William, Berger and Elston, 2005).
Discourse:	Communicative interchanges either in an uttered or textualised format (Wood and Kroger, 2000).
Emic:	An approach into how people sensitised to a particular environment think (Kottak, 2006).
Etic:	An approach to shift the thinking of a sensitised individual to the role of the 'researcher' (Kottak, 2006).
Health and Safety:	Regulatory system for reducing harm to individuals often in a workplace environment (Arrow *et al*, 1996).
Ingestion:	The consumption of a substance by an individual, typically through the mouth into the stomach.
Inhalation:	Breathing in a substance through the mouth or nose into the lungs (Palmieri, 2009).

Insurance:	A system whereby the risk of loss is equitably transferred from individual/organisation to another, alongside a payment (Birds, 2013).
Micro:	A scientific scale existing between one thousand and one hundred million times smaller than a metre (Dana, 2012).
Nano:	A scientific scale existing for phenomena between one hundred million and one billion times smaller than a metre (Dana, 2012).
Nanomaterial:	Materials with at least one physical dimension between one hundred million and one billion times smaller than a metre (Dana, 2012).
Nanoparticle:	Materials with all three physical dimension between one hundred million and one billion times smaller than a metre (Dana, 2012).
Nanotechnology:	The manipulation of materials at a scale between one hundred million and one billion times smaller than a metre, towards a commercial goal (Dana, 2012).
Pollution:	Release of materials into the natural environment that may cause negative effects (Dana, 2012).
Precautionary Principle:	An approach to risk management, where if an action or policy is suspected of causing a negative impact, and without supporting scientific evidence to the contrary, the activity is not carried out (Dana, 2012).
Registry:	An administrative database system for recording data (Bosso, 2010).
Regulation:	A legal device to shape conduct, with a spectrum of options being available between self and external agents setting and determining such activities (Brazell, 2012).

Risk:	Typically perceived as the potential of something negative occurring, although in its widest context, it can also be beneficial (Brazell, 2012).
Risk Management:	Procedures to identify assess and regulate risk (Dana, 2012).
Socio-Linguistic:	The interrelationship between the way that language and society influence each other (Wood and Kroger, 2000).
Therapeutic:	A substance to aid in healing or stabilising a disease state (Dana, 2012).
Toxicology:	The scientific study of chemicals and substances perceived or regarded as creating negative (toxic) effects (Brazell, 2012).
Waste:	Material that is perceived as unwanted or unusable (Dana, 2012).

Declaration

Unless explicitly stated otherwise, the work presented in this thesis is solely that of Sylvia Dean and has not been submitted for examination of any other degree. Material from published or unpublished work of others, which is referred to in the thesis, is credited to the author in question in the text.

Statement of Copyright

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Chapter 1. Introduction

1.1. Motivation and Aim

In an increasingly competitive and globalised marketplace, high technology research and development (R&D) through commercialisation is a common driver for many high technology companies to increase their market share and achieve growth (Wang, Lin and Huang, 2010). Due to the potential for physical and social benefit as well as harm from high technology products, the regulatory environment that high technology products exist within is often widely contested for how and why to regulate products (Baldwin, Cave and Lodge, 2012). Extant literature argues that while sector and 'product' specific regulation can enhance safety, and create some degree of certainty for manufacturers, it can also create barriers to commercial activities and increase the cost-to-market (Rogers, 2011). Regulation is thus rarely neutral, bringing both 'good' and 'bad' aspects depending on the stakeholder view used. Manufacturers must meet regulatory challenges if they wish to market their products, and depending on the type of regulation being applied, this can be no small undertaking. 'Clear' and understandable regulation is thus pivotal for commercial activities, particularly as the operating environments for high technology companies are often complex with high costs, irrespective of 'further' pressures brought from regulatory obligations (Jolly, 1997). Managers must be able to navigate and make sense of high technology regulations, and be able to make 'fit-for-purpose' decisions (Badawy, 2010). Inherent within all of these activities is the aspect of risk and uncertainty, which arises from the products themselves as well as manufacturer pursuits of regulatory compliance (Zhang, Mei and Zhong, 2013). As the level of technology increases there can be a propensity for the level of unknown risk and uncertainty to also rise, which is a factor that can be addressed through regulation.

In high technology arenas, technological product complexity can be particularly acute, particularly in business sectors including biotechnology, pharmaceuticals and nanotechnology. These sectors can have unique social and physical

considerations, which 'must' be addressed through regulation, to promote commercialisation but also to ensure public safety (Henderson and Clark, 1990). Where these aspects are not adequately controlled, commercialisation may fail, which is common in the pharmaceutical sector (CMR, 2006) and the public may be exposed to health risks as in the case of Thalidomide (Friedrich, 2005).

It has been suggested that nanotechnology will be one of the most important technology sectors of the 21st century (Delgado, 2010). It is the science and commercialisation of small products and materials, with a nanomaterial being between one hundred million and one billion times smaller than a metre (which is not visible to the 'naked' eye). The small size of these materials creates market opportunities for novel and unique size and surface related properties, but also brings new challenges for understanding the associated risks.

Within the field of nanotechnology there are three products or material classifications, which are (1) nanoparticles, which have all three dimensions within the nanoscale range; (2) carbon nanotubes, which have two dimensions within the nanoscale range; and (3) thin-films, which has one dimension within the nanoscale range. Nanoparticles are of interest to this study as they are at the vanguard of nanotechnology product commercialisation and are the most widely utilised of all nanotechnologies in a variety of sectors (SCENIHR, 2006).

Problematically, there is and has been a lack of understanding of how these technologies and products interact with humans and the wider environment, leading to much uncertainty and poorly defined risk (Fadeel and Bennett, 2010). Although there are and have been challenges to regulating nanoparticles, their relatively ubiquitous use in R&D and marketing has provided an opportunity to examine numerous regulatory aspects of nanoparticles. As such and due to the 'unique' regulatory landscape that nanoparticles exists within, i.e. limited specific regulation for a transformative and highly pervasive product class (Zonneveld, 2008), this study engaged with the regulatory aspects of this technology.

While many discourses have been provided and utilised for regulatory considerations of nanoparticles and nanotechnology from scientific sources, scientists have tended to favour promoting the benefits of these technologies, skewing public and key stakeholder perceptions, which may 'bleed' into regulatory discourses (Fadeel and Bennett, 2010). Beyond scientific constructions of nanoparticles and nanotechnology, wider and more varied socio-linguistic uses of nano-laden terminology i.e. 'ipod nano', has created discursive cultural references, which are not within scientific constructions of these products, i.e. they are small but not within a size regime of between one hundred and one billion times smaller than a metre. Thus the prefix 'nano' is used to promote the perception of high technology benefits rather than being scientifically nanoscale (Fadeel and Bennett, 2010). Regulators must navigate this set of discourses, as well as scientific, legal and other discourses to discern how and why to regulate nanoparticles.

Examining the phenomenon of nanoparticles from a physical perspective, much confusion exists for what, if any relationship a nanoparticle has to a larger bulk product. For example, can a silver nanoparticle be regarded as identical in risk to a silver ring worn on a finger? What if the ring is coated with nanoparticles? Aspects such as this are directly explored in this study to bring new understanding to this area, and highlight the challenge of regulating a relatively untested collection of 'small' products. Specifically and coupled with this is a consideration of the unknown nature of nanotechnology products, particularly for toxicity, environmental impact, and how the longer-term commercial aspects of nanoparticle products will play out (Oberdörster, Oberdörster and Oberdörster, 2005; Beer *et al*, 2012). It is well known that all of these aspects can result in consumers rejecting products if these areas are not adequately addressed (Sjoberg, 2000).

When considering regulation, it is critical to highlight that it is carried out, conceived and constructed through human actors. In high technology regulation, key stakeholder groups are commonly used to inform how something should be regulated, why, and potential benefits and risks from doing so. In line with this view, different regulatory stakeholders are addressed throughout this study as

necessary, to demonstrate various thoughts and concepts perceived necessary to the argument of regulating nanoparticles as nanomaterials, as opposed to their bulk counterparts.

Summing up this section and drawing on the study by Dana (2012), there is a general lack of understanding regarding nanoparticle regulation. Following on from other high technology arenas, aspects including the regulation of health and safety, insurance, and commercial aspects of nanotechnology, amongst others have been considered. As a starting point, the following section goes on to identify current perceived research gaps derived from extant literature.

1.2. Identified Research Gaps

As with 'all' research, there are important research gaps still to be filled, to bring to light new and vital knowledge within and between disciplines. Although based within law, this legal study draws on the arena of science due to the pivotal importance of scientific knowledge to this study.

The main theme for this study is the paucity of physical information for how nanoparticles should be regulated, where business innovation can still be facilitated and encouraged, but risk is minimised. While prior studies have focussed on nanoparticle regulation, there has often been a lack of consideration of the physicality of nanoparticles (McHale, 2008). Suggestions have however been made that regulation should be made on a case-by-case basis for nanoparticle products, but with little consideration of how this relates to nanoparticle physicality (Kobe, 2012). Other arguments have been made that alternatively that little to no regulatory changes should be made due to the high number of nanoparticle products on the market (Chaudry, 2012: WP), and if attempts were made to construct and implement nanoparticle specific regulations, it might harm commercial activities. Thus, this aspect is directly considered within this study for how to regulate within these arguments.

The political system which nanotechnology sits within cannot be ignored, as it is well recognised that many other high technology products, such as pharmaceuticals, biologics and medical devices operate within a neo-liberalist framework, where commercial innovation is a primary driver (Abraham and Lewis, 2002). Nanotechnology is found within these sectors, with this study attempting to explicate the regulation of nanoparticle products against this political zeitgeist. It could of course be argued that this debate has already occurred for prior technologies, but I contend that due to the inherent nuanced complexity and less knowable detection methods for nanoparticle and nanotechnology products, many other considerations must be made, particularly for issues such as toxicity.

The importance of language to law cannot be underestimated, particularly where there is technical complexity and opacity surrounding technical terms. While other disciplines have sought to engage with the refracting and restructuring medium of language (Rorty, 2009) for high technology products such as nanotechnology (Davies, 2011), little consideration has been paid towards high technology products from legal studies for this aspect. This study addresses this short fall by considering scientific language used, the meaning of technical terms and definitions, and where appropriate, contextualising this information against wider socio-linguistic constructions, which different stakeholders may encounter.

At present, there is a propensity to frame nanotechnology and nanoparticle products through ‘good’ or ‘bad’ stories, based on physical attributes, that may ‘bleed’ into their regulation (Kjølberg, 2009). Prior attempts to engage with this aspect have often been surface based, which has failed to capture the intricacy of nanotechnology physicalities. While helpful for simplicity, regulation arguably demands a more encompassing and nuanced approach where subtlety can be imbibed to more adequately reflect product realities, which in reality are rarely just good or bad.

Prior high technology products such as genetically modified organisms (GMOs) and Thalidomide (Sheetz *et al,* 2005) have resulted in speculative concerns in the former product and actual disasters in the latter, and left a mark of concern over

new products. Coupled with a high-level of uncertainty and opacity, and a fear of past regulatory 'failures' and general socially driven fears, risk must be addressed within this tempestuous set of discourses. From a commercial viewpoint, there is also the need to understand how nanotechnology products ought to be insured, if at all. Thus, these aspects are synthesised and examined as component parts and as a 'whole'.

Finally, the use of nanoparticle products and the health, safety and environmental impacts are considered. This is an encompassing view that has sought to cover this issue from product inception, all the way through R&D, manufacture, use, and disposal for workers and consumers. Prior studies have often considered numerous demarcated aspects of health, safety and the environment (Hull and Bowman, 2010), arguably at the expense of a product life-cycle overview. This study has therefore sought to expand this element, and take a more holistic overview and approach to explicate the challenges facing nanoparticle products.

After examining all of the research gaps, this study then (in Chapter 8) produces a broad but in depth consideration overviewing all of the these aspects, and contextualising them against extant literature, showing how the research gaps have been filled.

1.3. Research Methodology

From a more 'traditional' research methodological view, the method used in this study is more challenging to unpick and explicate than in other arenas such as the natural and social sciences. This is perhaps in part due to the natural and social sciences seeking to more overtly highlight the underlying methodological aspects such as the 'how', 'what' and 'why' where claims can be 'validated', 'verified' and/or warranted (Bryman and Bell, 2011). This is not to say that legal studies do not engage in research methodology, as they clearly do, but more that the underlying aspects are not necessarily 'voiced' in the same way.

While constructing a methodological approach, the question was continually asked, about how important it was to engage in methodological considerations. Perhaps like many aspects within law, this is a widely debated and contested area, with arguments ranging from 'you should use the legal method' through to, 'you are carrying out empirical research'. Problematically, and while acknowledging that this study is not based within an empirical paradigm, I drew on the notion that method is ultimately a part of methodology, and if explication of meaning can be aided by engagement with these considerations it should be carried out. Drawing on Hycner (1999), I followed the research methodology advice that the phenomenon should dictate the method. Thus with this being a legal study examining high technology and in particular nanotechnology and nanoparticle regulation, without empirical research, I undertook a method that can broadly be considered in line with a 'soft' notion of content analysis. While content analysis can be taken as a varied collection of methods (grounded within different methodological underpinnings), from the perspective of this study, it is a way of meaningfully engaging with texts. Although many content analysis methods can focus on elucidating aspects such as word frequencies to elaborate potential social structures etc. this study has not sought to do so. Instead of fully imbibing a concretised method, a perspective has been selected. In practicality, this means that I have engaged with texts as a means to infer discursive, social, scientific and legal structures from within them, and what might in many ways be considered an 'opening out' of the phenomenon. An example of this can be taken from the word nanotechnology, where in section 3.3 (and following sub-sections) an attempt is made to unpick how the word nanotechnology is split into 'nano' and 'technology' and how different social, linguistic, scientific and legal structures influence and are influenced by this word. Thus, no singular meaning of any word is concretised, but multiple interpretations accepted showing the distortive capabilities of language (Searle, 2011), and the difficulties for law, particularly in engaging with high technology albeit with a need for discursive clarity. Due to the expansive and incomplete nature of nanotechnology discourses, this study might be considered a bricolage of important emergent themes from what is at present an incomplete picture of nanotechnology and nanoparticle regulation. At this early formative stage, varying degrees of attention have been paid to different aspects of regulation, and as such, an

incomplete picture put together. Drawing on what might be considered a 'best fit' content analysis approach, this study has pulled together what were considered the most pivotal themes.

Alongside the methodological factors discussed so far is how I as the researcher interacted with this study. In positivist and predominantly natural science based studies, a researcher will predominantly undertake the position as 'the researcher', where claims are made about research being objective, attempting to minimise uncontrolled interactions with the research i.e. where the researcher is 'objective'. At the other end of the spectrum, and often found within non-natural sciences research, a researcher will undertake an embedded position within their research, where they acknowledge and 'thrive' in their claims of subjectivity as being part of the research. I addressed this aspect through the 'framework' of emics and etics (Kottak, 2006). In principal, this led me to acknowledge my sensitisation for how people from a particular environment think, known as an emic approach and broadly subjective. My emic sensitisation occurred through my having engaged with the commercial aspects of nanotechnology companies operating within the shade of high technology regulation. This gave me insights into this environment but this also had the potential to bias my construction of this study. The important aspect for having undergone emic sensitisation is the acknowledgement of this fact, bringing it to life, and contextualising it against an etic approach. Undertaking an etic stance obligates a research shift on my part as the researcher to focus on being 'the researcher', where knowledge must be routed through the lens of extant literature, pulling the research and the researcher towards objectivity. Drawing on both an emic and etic approach provided a unique opportunity to utilise in depth culturally derived knowledge, and then contextualise it as the researcher, and I argue that this gives a greater potential to subjectively and objectively mirror the reality and phenomenon of this study, i.e. nanoparticle regulation.

1.4. Research Question, Aim and Objectives

Taking an emic approach through my sensitisation to the sector, and an etic stance from extant literature, the following main research question was used to address gaps in the literature and guide this study:

1. How should nanoparticles be regulated so that risk is minimised while business innovation and commercialisation is encouraged?

It is accepted that a variety of stakeholders may be involved with regulation and is addressed throughout this study. Drawing on this main question and theme, it is recognised that other minor themes as questions would need to be drawn out to complement the main question, and include:

2. How are high technology products regulated, and how does the neo-liberal regulatory framework influence this?

3. What are nanotechnology and the product class of nanoparticles, from a scientific and socio-linguistic perspective?

4. How are nanotechnology and nanoproducts used commercially, and what are the perceived negative and positive attributes potentially influencing their regulation?

5. How are nanoparticle products perceived from a risk perspective, and how does this influence their insurance?

6. What are the health, safety and environmental implications of nanoparticle products, and how might regulation be used to address this issue?

7. What are the regulatory approaches to nanotechnology and nanoparticles that might best result in regulation promoting innovative commercialisation while addressing needs to mitigate risk?

Building on the research question and extant literature, and previous questions, the research aim is:

> To examine the rationales for regulating nanotechnology and nanoparticles, with a predominant focus on risk and benefits, drawing on Europe and the USA as appropriate.

The approach taken for these questions and aims is set out in the following three research objectives:

> 1. Through a literature review and examination of current regulatory discourses, to understand how the arguments for and against nanoparticle regulation are constructed;
>
> 2. Based on (1) to contextualise these discourses against the underlying rationales for nanoparticle and nanotechnology regulation;
>
> 3. Based on (1) and (2) to draw the literature together and make suggestions for the regulation of nanoparticles and nanotechnology products.

Utilising concepts from the previous section on research methodology, the approach set out in this section, enables the fusion of subjective and objective approaches, coupled with knowledge derived from emic knowledge but also contextualised through the lens of the researcher, through an etic stance.

Drawing on the research questions, aims and objectives, the following section details the significance and contribution of this research as it relates to the extant literature.

1.5. Significance and Contribution of this Research

The research carried out in this study has provided an in depth examination of the challenges surrounding and facing the regulation of nanoparticles, as well as highlighting challenges facing nanotechnology more generally. Prior to this study academic inspection was limited to either legal or scientific discourse, as predominantly separate studies, with few studies having attempted to engage with nanotechnology through multiple academic lenses including law and science.

As a starting point, this study has argued that nanoparticles and nanotechnology are not regulated on any specific quality inherent to their nuanced physicalities as nanomaterials. Instead, current regulatory systems have been used to varying degrees. Thus, depending on the product application, sector, and perceptions of non-nanoscale products, different aspects of nanoparticle physicalities have been 'unintentionally' regulated. The current lack of specific regulations for nanotechnology can perhaps be argued as in keeping with neo-liberal regulatory underpinnings to facilitate product commercialisation. This has however been at the expense of a more rigorous approach to nanoscale phenomena.

Unfortunately, while product commercialisation is facilitated through neo-liberalist approaches, the physicality of nanoparticles dictates they are not a mirror image of larger products, and potentially a poor physical reflection of the way that larger products behave. Coupled with a potential to change their size, shape and toxicity due to processes such as Ostwald Ripening, the current regulatory frameworks fail to capture many aspects of product physicalities. Assumptions that nanoparticle products will function as bulk products is often mistaken, and this study has highlighted the 'how' and 'why'. Looking back at forerunner technologies such as microtechnology, which also came about through miniaturisation, there has perhaps been a propensity to assume that nanotechnology is simply a linear extension of this technology. This however is not the case, as although nanotechnology products are smaller than microtechnology products, 'no' new physical properties were displayed by down sizing for microtechnology, where new properties are clearly observed for

nanotechnology. Importantly, while novel properties have been demonstrated from scientific studies, there has been a propensity not to examine at the same level, the potential risks from nanoparticles. This has led to a paucity of data, meaning that it is more difficult to construct risk assessments to mitigate problems associated with toxicity etc.

A critical foundation for engaging with nanoparticles as a part of nanotechnology, led to the examination of some of the language-based aspects of these two words. In particular, numerous non-scientific influences have been highlighted for both nanoparticles and nanotechnology as unhelpful. Instead, the recommendation from this study is for regulators to utilise scientific constructions and definitions, with the acknowledgement that at present there is no legal definition for either word. Scientific constructions, although potentially varying are more likely to ground the phenomena of nanoparticles and nanotechnology as being nanoscale physical entities, with novel properties, potentially suggesting a greater focus towards treating them as novel materials, not well captured under current regulatory systems. Although, this statement must be clarified, as is described in this study, how well a regulatory system captures the phenomenon is based upon aspects such as product physicality, and application.

The aspect of risk is critical for nanoparticle and nanotechnology regulation, as it is unlikely that current regulations will enable toxicity to be unpicked and elucidated. This may have profound impacts on the future of nanoparticle and nanotechnology products, where risk assessments are at some level unworkable due to the unknown nature of nanoproducts, based on a lack of rigorous scientific testing. In turn this may echo into the insurance of these products, where there is currently much debate about how nanoparticle products should be insured, or more bluntly at times, whether they should be insured at all. Pivotally, more physical data on risks is needed from fit-for-purpose testing.

The approach used in this study, has facilitated novel findings as discussed so far and has highlighted new ways of looking at the challenge of nanoparticles and nanotechnology as not only a scientific phenomenon but an arena that must undergo rigorous investigation from the arena of regulation, potentially resulting

in specific regulations being discussed and brought into being. I argue that the strongest aspect of this study has been grounding the approach within the physicality of nanoparticles and nanotechnology, something that no other study has done. This has enabled a view that is in some ways similar to other high technology products that are also high risk, such as pharmaceuticals, biologics and medical devices. Drawing on these other high technology product areas, the notion of examining risk related to toxicity through the use of different trials is thus nothing 'new'. However, it is unlikely that these different regulated areas, while in their current formats would enable nanoparticle toxicities to be much better understood. My main recommendation from this study is therefore, that an approach is taken to regulate nanoparticles as separate and distinct from their bulk scale equivalents, unless there is evidence to the contrary. This would change the current status quo, which seeks to regulate nanoparticles as their bulk materials. It is too simple to regard nanoparticles as a mirror reflection of larger materials, particularly where novel composite materials have no bulk equivalent. At some level this would require manufacturers to engage with increased testing to demonstrate a level of 'safety' relevant to product usage. For example, a higher level of nanoparticle toxicity might be more acceptable for a therapeutic drug 'curing' an individual from a life threatening illness, in comparison to nanoparticles in clothing.

In suggesting a move towards regarding nanoparticles as separate from their bulk counterparts, multiple aspects of different regulatory systems may require adjustment, from manufacture through to use and disposal. Creating national and international nanomaterial databases, with required testing, will reduce long-term commitments to test materials that have already become well understood. Arguably, with further testing, a more nuanced understanding of the behaviour of nanomaterials will be elucidated, building a platform of knowledge that can be implemented in various regulatory systems such as REACH and ISO. With such limited information at the present other than there being differences between the bulk and nanoscales, it is difficult to suggest further changes, as ideally basing regulation on product physicality should be evidence based, due to product testing.

1.6. Thesis Outline

Chapter 1. Introduction

This chapter introduces the study, research question, aim and objectives as well as detailing the significance of the research carried out in light of contributions to academia and regulators. The structure of the thesis is also presented.

Chapter 2. Regulation of High Technology Products

This chapter examines the regulation of high technology products, with fundamental aspects being explored that underpin this study. As such the history of regulating high technology products are considered alongside how innovation is regulated. With the aim of this study being the examination of nanotechnology products, the forerunner product class of microtechnology is also considered, leading on to the current status of nanotechnology regulation. Finally, a discussion is made of neo-liberal regulation, which is the framework that nanotechnology operates within.

Chapter 3. Nanotechnology and Nanoparticles

This chapter focuses on the area of nanotechnology, and in particular the product class of nanoparticles is examined due to this being a vanguard technology. The difficulty of varying definitions within science, wider culture, and no legal definition is considered, alongside an in depth exploration of nanotechnology as a physical commercial phenomenon. An explanation of the differences between nanoparticles, thin-films and carbon nanotubes is also made, as well as how nanotechnology is set apart from other technologies. Finally, an exploration of underlying drivers for regulating high technology products is made.

Chapter 4. The Commercial use of Nanotechnology and Nanoparticles

The focus of this chapter is on the commercial use of nanotechnology and nanoparticles. The two main aspects of benefit and risks are set up for later

discussion in this chapter, particularly for what is attractive about nanotechnology, potential applications, but also detrimental considerations that must be made, including product uncertainty and toxicity.

Chapter 5. Risk and Insurance

The focus of this chapter is on risk and insurance, and how these aspects are influenced by the potential benefits and often-unknowable characteristics of nanoparticles and nanotechnology. Thus the notion of risk management and risk-benefit ratios are examined, alongside the concept of acceptable risk. Importantly this section looks at risks associated with prior technologies, which include asbestos and the link to similarities with nanotechnology. The Precautionary Principle and how it is applied is discussed alongside risk analyses and self - regulation. The second part of this chapter is devoted to insurance, which is necessary to observe how insurance underwriters view nanoparticle products and cover them against unknown risks and hazards. This includes sections on how companies engage with nanotechnology and insurance, commercial insurance coverage and the future of nanotechnology insurance.

Chapter 6. Health, Safety and the Environment

This chapter focuses on the arena of health, safety and the environment, with an in depth examination of the three main routes of human exposure, including dermal penetration, inhalation and ingestion. The dangers of working with nanoparticles are highlighted with exemplar areas of food, medicine and cosmetics. These areas are considered for a variety of environments ranging from manufacture to home use.

Chapter 7. Regulatory Approaches to Nanotechnology

The focus of this chapter is on national and EU regulations already in place for high technology products and questions whether they are suitable for nanotechnology. This is against a backdrop where current strategies predominantly treat nanotechnology products as equal to larger bulk scale

materials and products, even if the benefits and risks are different. The regulatory landscape is considered for how disasters such as Thalidomide and asbestos can be avoided, potentially through the use of Nanomaterial Registries such as those set up in France, Belgium and Denmark, plus the voluntary registries that are in the process of being set up in the USA, by DuPont. This is alongside the use of REACH and the Precautionary Principle for mitigating risk and aiding in commercialisation.

Chapter 8. Discussion and Conclusions

This chapter pulls together all of the research findings and main themes derived from this study, with an examination against extant literature, to construct a discussion and conclusions. Building on these aspects, contributions for the knowledge base derived from the research question, research aim and research objectives are highlighted as well as implications for regulators. Finally, research limitations are considered alongside recommendations for future research.

The following chapter starts an examination of the extant literature on nanotechnology and nanoparticles.

Chapter 2. Regulation of High Technology Products

2.1. Introduction

This chapter sets out to examine the regulation of high technology products, and is broadly driven by the question 'how are high technology products regulated, and how does the neo-liberal regulatory framework influence this?' To answer this question, multiple themes are examined including the history of regulating high technology, the regulation of innovation, neo-liberalist regulation and how the forerunner technology to nanotechnology known as microtechnology was regulated. Finally, the current regulation of nanotechnology is examined.

Before these aspects are considered in more detail it is worth pointing out that there will always be arguments made for and against regulating technology products and services. Where there are many stakeholders, many divergent views on how to regulate technologies are often voiced with competing reasons why. Simply, it must be remembered that any regulation is a balancing act between multiple discourses and rationales. The complex physical nature of high technology products means that it can be difficult to discern risks and benefits, to construct fit-for-purpose regulations based on product physicality. It arguably necessitates in depth product knowledge, whereby the risks and benefits of products can be rapidly and more easily understood. However, and as will be discussed throughout this chapter, this is not always the case, as different individuals utilise different levels of knowledge.

As a starting point to address the research question posed for this chapter, the following section starts to construct an answer by considering the regulation of high technology products.

2.2. Regulating High Technology Products

High technology products are physical entities that can be considered at the 'cutting edge' of technological innovation, and with product advances in any sector, what is considered high technology today, may slip into being a 'common place' or low technology tomorrow. As technology products become better understood, there is the potential to regulate them more effectively based on known information, rather than speculative assessments, although the debate can always be continued for how well any product is really known. It is important to understand however that while I maintain the importance of regulation based on product physicality, this is but one of many parts of product regulation. However, as this area is often neglected for high technology products, this study has undertaken to engage directly with this issue. Coupled with these aspects is the pivotal aspect of the stakeholders carrying out regulation, as within human actors, regulation could not be achieved.

As might be expected from any area with multiple drivers and stakeholders, explicating what regulation is, is no small challenge and is often contested (Mitnick, 1985). A commonly discussed construction of regulation is that by Selznick (1985), who sets out that regulation is positioned as a sustained and focused control, exercised by a public agency, often on the behalf of a state. Drawing on the suggestion of Black (2002), it is perhaps more helpful to regard regulation as being used in the following ways, including (1) as a specific set of commands, (2) as deliberate state influence, and (3) as forms of social or economic influence. Within these notions is often the idea that regulation is simply there to prohibit and restrict behaviours, as in a 'red light', when in actuality a broader perspective is more useful as it engages with the concept that regulation can also be a 'green light' whereby behaviours are facilitated or encouraged (Harlow and Rawlings, 2009).

Regulation of products, including high technology is predominantly orientated towards adjusting behaviours, achieved through a mix of 'incentives' and 'punishments'. As Brownsword (2007) argued, high technology regulation sets

out to 'command and control' through the state. Black (2002: 19) went on to define this as:

> *'The sustained and focussed attempt to alter the behaviour of others according to defined standards or purposes with the intention of producing a broadly identified outcome or outcomes.'*

This type of regulation can be undertaken by a variety of regulatory stakeholders, not just government, so that a range of outcomes albeit positive or negative can be obtained, as well as encouraging certain types of behaviour (Brownsword, 2007). For example, and drawing on the pharmaceutical sector, the three areas of safety, efficacy and quality of products are heavily addressed through regulation (Abraham and Shephard, 1999), with an aim to balance societal needs and safety, with those of industry, where bluntly commercialisation of innovative products 'should' be encouraged and risk mitigated (Wiener, 2004).

High technology products are often unique in the way that they are researched, developed, and sold into the marketplace. While there are commonalities, heavy regulation for risk-laden high technology products has greatly influenced the way that the market operates (Abel-Smith and Grandjeat, 1978). The nature of the regulatory forces has meant that there are market imperfections in not only the supply, related to patent protection, and demand, where medical organisations often dictate what product should be used with a patient (Mossialos and Mrazek, 2004).

Regulation is not fixed immemorial, but is instead a fluid socio-historic construct embedded within culture, without permanence, where social, economic, medical and technoscientific drivers may change regulatory trajectories. As Gaudilliè and Hess (2013) commented:

> '*ways of regulating are therefore categories or frames used in thinking about, choosing between, and organizing practices that are not "give," but constructed, in a given duration, each representing a*

"grammar of action" that works in combination rather than in isolation'.

Thus while it is perhaps easy to imagine that all regulatory pathways are along a beneficial evolutionary pathway, it is perhaps better to consider that the path is adaptive to current and perceived needs. As Gaudilliè and Hess (2013) stated:

'*Regulation may then be viewed as a series of dispositifs, or purviews, not only targeting commercial practices but also aiming to define production standards or to set norms for medical uses. Regulation is not exclusively a problem of government control and marketing authorizations; it is also a problem of legitimate patterns of action within the laboratory, the production plant, the doctor's consultation room*'.

Approaches often taken towards regulating high technology products include different regulatory frameworks, which might include Government Guidelines, Directives, Regulations and Acts to cover a host of potential aspects from inception through to use and disposal (Hull and Bowman, 2010). For example, within the EU, State Law can be useful for setting out what is required but through wide distribution requirements, facilitating regulatory uptakes, it has however been criticised as being too cumbersome, rigid, slow and costly (Moran, 1995; Sinclair, 1997) and being a barrier to commercialisation. This can be problematic in rapidly evolving fields such as nanotechnology, suggesting that in the short term, State Law regulation *'may not be the most appropriate or effective way to regulate specific areas of the technology'* (Hull and Bowman, 2010). Stepping beyond this approach is the potential to use 'soft' law, where government has a limited role in its operation, although as demonstrated in high technology sectors such as pharmaceuticals, medical devices and biologics, regulatory agencies are often heavily involved on the behalf of the state (Jackson, 2012).

The many types of soft law regulation used to regulate high technology products include industry codes, risk management frameworks and voluntary codes of

conduct as they are able to adapt to a changing environment more quickly than state based regulation (Ayres and Braithwaite, 1982; Sinclair, 1997). This arguably can help promote innovation and creativity as it is often said that regulation stifles innovation (Hull *et al*, 2010: 78). Black (2002: 25) reminds us *'self-regulation is neither a new phenomenon, nor one which is likely to disappear,'* but it is not without controversy as it is often *'accused of serving the interests of industry above society'* (Hull and Bowman, 2010: 79). Soft law is discussed in more detail in Chapter 7.

It is against this backdrop of regulatory approaches that nanotechnology and nanoparticles must be considered to address risks while promoting commercial innovation. To further understand high technology regulation, the following section goes on to consider a brief history of regulating high technology.

2.2.1. A Brief History of Regulating High Technology

Technology products, including high technology, have a long history of regulation in one form or another, which has included numerous aspects of product life cycles from inception through to manufacture, use and disposal (Daemmrich, 2004). In practicality, it is difficult to make broad and sweeping statements that encompass all high technology products throughout any time period, as due to application, sector and perceived risks and benefits amongst other drivers, there can be substantive variation. However, and to try to unpick some major themes from high technology regulation, an examination within this section of pharmaceutical products is made, to try to elucidate drivers to regulate and how this has been achieved over the years. As will be demonstrated, while there may well be a propensity for regulation to be constructed as a legal 'matter' this is somewhat misleading, as while law is often a vital component, there are many other stakeholders and drivers beyond law, which feed into law to assist in regulatory decision-making.

Examining pharmaceutical product regulation, there is a long and often incomplete history, and while it is not the purpose of this section, to dig too

deeply, it is intended to highlight the challenges and frequently recorded rationales for regulating technology products. Looking at an early example of a health product that was subjected to regulation, is the medicine 'Mithridatium', which in 'actuality' was a collection of products, recorded as having been prepared, and used by King Mithridates VI in 120 BC (Mayor, 2003) with it being used until the 1780s. Even though this 'product' was used until the 1780s, initial regulation for manufacture was brought in via the Apothecaries Wares, Drugs and Stuffs Act in 1540. The early to middle part of the last millennia was arguably the start of medical regulation in a way that has some similarity to modern times. For example, the Salerno Medical Edict issued by Fredrick II of Sicily (1240) stipulated that medicines must be prepared in a similar way, which can be linked to current manufacturing practices, whereby there is still this necessity, albeit to a much higher standard today. These previous regulatory practices also resulted in the further move of health care related technologies to being recorded in documents, via pharmacopoeias, and although pharmacopoeias are still used, there has been a wide range of new documentary systems for regulation. In essence, what can be gleaned from this practice was a need to record and at a relatively minor level monitor the production of medicines to ensure a basic level of quality in manufacture. In comparison to techniques and regulatory practices used in the present time, such practices were limited, but arguably created a very basic framework, from which modern regulatory systems for safety, efficacy and quality can be traced back to.

In Britain, regulation has a history from at least the Tudor and Stuart periods (Ogus, 1992). It was not until the nineteenth century however that regulation 'exponentially' increased, alongside a number of regulatory institutes, including for example public health (Craig, 2003). This rapidly expanded into goods and services bought and sold, where controls were introduced for prices, safety, and quality of products and services (Foreman-Peck and Millward, 1992). From the 1930s, the number and scope of regulation increased, which increased again post-1945. While regulation increased, this ultimately led to many varied debates about how well regulation served society and different stakeholders (Lodge, 2008), which is still on going.

As is perhaps not surprising, regulatory systems have changed substantially over the years, and earlier iterative forms often now only bear a weak resemblance to today. With advances in knowledge and technological and scientific innovation, particularly from the natural sciences, the ability and potential to manufacture higher technologically based products increased. These advancements created a greater ability to understand how products can negatively interact with biological entities such as humans. Examples of this were the 1937 poisoning of over one hundred people in the USA from the use of sulfanilamide elixir with diethylene glycol (Mann and Andrews, 2014), where the use of the diethylene glycol solvent had not undergone safety testing. This incident was a driving force for the introduction of The Federal Food, Drug and Cosmetic Act in the USA, which required market notification of new drugs starting in 1938. In countries lacking or with low-levels of regulation for contamination of medicines, deaths due to the presence of diethylene glycol have still been noted (Bogdanich and McClean, 2000). Not surprisingly, contamination occurring during manufacturing practices has not been limited to diethylene glycol, as numerous other contamination incidents with different chemicals also took place over the past centuries (Thompson, Poms, Martin, 2012). Importantly, as knowledge into adverse effects from products increased, so did the ability to understand how they could harm humans, and particularly through biochemical damage. With this knowledge came further regulatory drivers to safeguard public health, coupled with trying to safeguard commercial innovative activity.

A further critical milestone in the development of high technology health care regulation was the introduction of Thalidomide into the marketplace, which posed the greatest challenge to regulated medicines in the past century, and which became known as ‘the Thalidomide disaster’ or the ‘Contergan scandal’ (Friedrich, 2005). Simply, and disturbingly, the use of Thalidomide led to the death and deformation of foetuses and babies, from pregnant women using this product. The impact on the regulatory landscape from this disaster cannot be underestimated, as the fear of another such scandal is frequently discussed in many regulatory circles (Mann and Andrews, 2014). Since this disaster, there has been much regulatory movement to reduce the potential of another scandal, and with nanotechnology often being claimed to be poorly understood for health risks,

Thalidomide is frequently mentioned as a driver to avoid harm from nanotechnology products. In many ways, such statements are of course overly simplistic, but as will be shown throughout this study, there are very real potential risks from nanotechnology and nanoparticle products, which if not handled and regulated accordingly could easily dwarf the Thalidomide scandal. While numerous aspects have been raised in this section, the following section goes on to consider the paradigm of neo-liberal regulation in which nanotechnology and nanoparticle products exist within

2.2.2. Neo-Liberal Regulation

Over the past decades, and facilitated by paradigmatic shifts in regulation by the Thatcher government in 1979, the UK, moved closer towards neo-liberal regulation for technology based products. In practicality, this shift did not occur in the UK alone, as changes were also noted in numerous European States, and the USA. One of the most important goals of neo-liberal regulation was the reduction in state-based intervention in state economies. Technology companies, particularly those involved in high technology R&D, manufacture and sales, where regulatory obligations were arguably the most onerous, championed a major driving force for this change. It has been suggested that in the UK, the Thatcher government was sympathetic to industry, seeking to adjust the regulatory system to aid what has been considered the commercialisation of innovative products (Abraham and Lewis, 2002). Thus, changes were implemented towards enabling more rapid commercialisation, where products could be brought into the commercial arena and marketed more easily through lower regulatory barriers, reducing costs to these companies. This period has been a political attempt to reduce state intervention with the market place '*subjecting the state to competitive tests of 'the market', and elevating individual consumer choice above the state as a form of collective decision-making*' (Davis and Abraham, 2013: 137). According to Fisher (2009), this has been a process to liberalise medical markets, through relaxing regulations, and to reduce barriers to innovation and commercial exploitation of technologies.

Looking at the pharmaceutical industry as an insightful exemplar for neo-liberal shifts, moving towards neo-liberal regulation resulted in a several fold increase in products being brought to market. This raises many potential questions, but with two of the most pertinent being, (1) did this regulatory shift enable innovative products beneficial to society? And (2) how did the 'easier' regulatory system impact on elements such as risk mitigation from potentially dangerous products? Addressing decreasing regulatory burdens, it became possible for companies to rely on various sets of data for products already in the market place, thus negating a need to carry out 'replicate' testing. Unfortunately, rather than stimulating new product innovations, the R&D system became skewed by companies preferring easier routes to market, where they would reject innovative product design, on the basis that full-testing would still be required. Unfortunately, this has meant that much product R&D and commercialisation has had little benefit to society, and it could be argued that it has hindered novel drugs being discovered (Kaitlin and Di Masi, 2000). This is of course a somewhat sweeping statement, but one that I argue predominantly holds. Within this main R&D shift based on regulation, there are some benefits to society, such as potentially cheaper products, but there is still much to unpick and elucidate for how these structural regulatory shifts will go on to impact on product regulation in and outside of pharmaceutical drug production.

Examining the second aspect of regulatory shift impacts on risk mitigation, it is worth highlighting that neo-liberal regulation has been described as an '*ideology of innovation*' (Doran *et al*, 2008: 40). Expanding on this, it has been further argued by Davis and Abraham (2013: 137) that:

> '*neo-liberalism perpetuated the misleading ideology that innovation and public health benefit were as one and that, therefore, the goal of regulation should be to promote innovation per se, or at least that a drug's claim to innovative mechanisms should be given great emphasis based on expectations of health benefits*'.

Although caution should be taken from just drawing from the pharmaceutical sector, examination of other high technology health care related sectors such as

biologics and medical devices also indicate a similar problem, whereby a greater emphasis needs to be placed back on product safety and risk mitigation. Examining nanotechnology and nanoparticles, it would appear that there is a similar challenge, whereby rapid commercialisation has been encouraged for products. Drawing a similarity to the pharmaceutical sector, while on a technical point, many nanotechnology products are indeed innovative on the basis that there is something new and usually a nanomaterial, but it is often debatable whether adding nanomaterials to products enhances anything for society, or more the manufacturers.

After examining the neo-liberal underpinnings in this section, the next section goes on to consider a critical aspect of neo-liberal regulation, that of risk.

2.2.3. Regulating Risk

Understanding and working with risk is an inherent part of neo-liberal regulation where products may go to market with variable assessments carried out on product safety. There is of a common perspective that regulation is inherently about controlling and where possible mitigating risks, spanning across many aspects of our lives (Rothstein, Huber and Gaskell, 2006). As stated by Baldwin, Cave and Lodge (2012: 83) '*more formally, risk is usually defined as the probability of a particular event (or hazard) occurring and the consequent severity of the impact of that event*'. Importantly, a distinction can be drawn between risk and uncertainty, although in a common sense, they are often used interchangeably. Uncertainty is thus inherently difficult to measure, whereas risk can be measured (Knight, 1921). Thus product risk is concerned with 'the measureable' aspects of their design, R&D, manufacture, use and disposal. Complicating risk is the element of uncertainty, where as in the case of nanotechnology, many aspects are at present unknowable, or at best difficult to measure and produce a risk assessment based on elements of risk uncertainty.

Looking more broadly at risk, Beck (1999) has argued that we are now part of a 'risk society', where as a consequence of manufacturing products, we are at the

‘mercy’ of their associated risks, which necessitates a pro-active stance towards regulating their risk. The variety of risks arising particularly from high technology products has meant that states have implemented regulatory bodies often as ‘experts’ who have ‘the knowledge’ to be able to identify and recognise risk, that might be unseen by those without high-level specific knowledge. Within this zeitgeist, problems have arisen, particularly for high-technology products over risk-based language including terms such as ‘safe’ and ‘unsafe’. While it is possible to accept that all products have an underlying level of risk attached to them, it seems strange to consider the use of a product that is unsafe. Healthcare products often straddle the safe-unsafe divide, where for example pharmaceutical drugs are not to be used without authorisation, to protect the public from potential harm. Thus we have products that by their nature may cause serious harm to a person, but yet, when weighed up against potential benefits, they should in principal have more to offer through benefit, than through harm. This concept is expanded on many times in this study for nanotechnology and nanoparticle products, where there is often a perceived level of risk, yet the products are sold. Perhaps most problematically for nanoparticle products are their unknowable nature, where current regulatory testing protocols often are incapable of detecting real harm.

When considering the regulation of risk, it is easy to fall into the fallacy of not taking into account the human element and challenges associated with this aspect. In other words, no matter what risk regulation management practices are put into place, these are human ideas, constructions, and practices, which have their weaknesses within this area, and arguably their strengths too. For example, product stakeholders and consumers are all immersed in a sea of discourses where technology is framed differently, and an individual product technology may have to be negotiated for how risk is regulated and managed within this sea.

Stepping beyond the discursive elements from wider conversations and media discussions about risk, is the requirement to assess and define risks, which themselves are still within the arena of the former discursive arena. While it may appear simple to suggest that the most severe risks most easily identifiable should be regulated as a matter of urgency, in practicality, this is not an easy

undertaking (Krimsky and Golding, 1992). Most pertinently, the question can be asked, 'what should be looked for that is indicative of a problem?' This is not easy to answer, and against low-level and slow to develop visible factors to highlight risk, is the other problem of the 'black swan' that even with the 'best' data available, nobody could foresee the actuality of the problem (Brooks, 2007). Coupled with this is the difficulty of trying to discern when a risk might occur, as different environmental conditions, human interactions and product uses (intended and unintended) might also influence the categorisation of risk.

Due to the small size of nanotechnology and nanoparticles, there is a potential that products might display voluntarily imposed risks and socially imposed risks. The former is a consequence of for example purchasing and using a product, where risk can be mitigated by the 'correct' use of a product, or more simply not purchasing it. Socially imposed risks occur for example from a technology entering the environment, such as nanoparticles entering the water system from every day product usage. In this case, consumption choices will not necessarily reduce risks, and regulations must encompass both of these two aspects.

According to Fischhoff *et al* (1978), a critical challenge facing risk studies is how to engage with risk, through perception, assessment, quantification, and a response should the need arise. All of these approaches work on a notional basis that the issue is often not about an event occurring in actuality, but more about other factors. These factors include, (1) technical perspectives, (2) economic perspectives, (3) psychological approaches, and (4) cultural theory (Gormley and Peters, 1992). Briefly, (1) technical approaches take a view to assessing the potential frequency of an event occurring over a given period of time, thus setting out a probability. This approach often also seeks to understand not only the probability of an event occurring, but often the social acceptability of the event, should it occur. Looking at (2) economic perspectives, comparisons between risks and benefits can be carried out, and has found particular favour in regulatory decision-making. Arguably, this is more subjective than the technical approach but is able to highlight many more factors in the complex mix of regulation. Moving onto consider (3) the psychological approach, draws out how individuals and groups perceive risk, and their preferences for their perceptions.

This area of risk assessment is open to examining wider socio-linguistic constructions, such as from the media, where a forerunner technology such as Thalidomide may be influencing current perceptions. Finally, (4) cultural theory suggests that individuals construct risk through cultural group biases, where they form attitudes for how to perceive a risk. Importantly, and while four aspects of risk have been discussed, it is likely that with such blunt segmentations, the reality is more complex and nuanced, but that these four areas can highlight different understandings of risk-laden products. Some of these aspects are given greater examination in chapter 5 for nanotechnology and nanoparticles.

Moving on, the next section pulls together the current status of nanotechnology regulation, and is a pivotal foundation for building further knowledge throughout this study.

2.2.4. The Current Status of Nanotechnology Regulation

Concepts and practices associated with nanotechnology do not sit in isolation from previous and current product regulations. Thus, a brief regulatory glance back to how forerunner technologies have been regulated is carried out, to better understand the current state of nanotechnology regulation. Expanding on Section 2.2.1, an initial consideration is made of the forerunner technologies of microtechnology products and how they were and are regulated.

When addressing nanotechnology, which is the technology of 'the small' the questions can be asked, 'but didn't microtechnology come first? And how was that regulated?' Addressing these questions, it is important not to construct nanotechnology as being a simple downsizing of microtechnologies, where microtechnology exists between one thousand and one million times smaller than a metre and nanotechnology between one million and one billion times smaller than a metre. The way that microtechnology and nanotechnology products work are not necessarily the same, or by linear extension, as at the nanoscale, new physical properties are observed, which do not occur with microtechnology products. In other words, microtechnology products are miniaturised versions of

bulk scale products, with new capabilities but with similar physicalities. In practicality, this means that there is little difference between a larger object and a microscale object other than that of size. However, physical properties can vary substantially between the nanoscale and the micro/bulk scale. Thus, little was done to regulate microtechnology products as microtechnology products, and regulation was carried out through existing systems, as little concern was raised about any increased risk from producing a downsized technology class. This has remained the case until the present, and it is unlikely this will change any time soon, as only limited evidence exists for microtechnology toxicity (Simak, 2015).

Moving on to examine nanotechnology products, the novel and 'desirable' effects may also lead to a much higher level of unknowable risk than any other set of products. This is compounded by the pervasive nature of commercialisation, with a high number of products already having gone to market. As nanotechnology matures and as the number of products containing nanomaterials available in the global market place increases, the debate concerning the necessity for nano-specific product regulation has become more intense (Bowman, 2010). This poses the question for how nanotechnology products are currently regulated. The simplest answer to this question is that, at present, they are regulated under current regulatory systems and not specifically as nanotechnology products. More simply, there is yet to be any adjustment to any regulation to specifically require adjustments to testing of materials or products based on them being nanoscale. In principal, this means that all nanotechnology products go through their regulatory journeys, with risk assessments and any other consideration being made as an equivalent to the micro or bulk scale. From a regulatory perspective this adds 'no' further requirement for companies engaged in nanotechnology commercialisation. This however may be an overly simplistic view. As although there may be no requirement, companies are free to engage in further regulatory procedures outside of any requirement, but there is no obligation to do so. This theme of 'no' current regulation is one that is explored throughout this study, and while there has been a predominant exploration of a few commercial sectors and nanoparticle applications, it may well be the case that there is a limited like-for-like between products. For example, if looking at pharmaceutical regulation,

there is a requirement for safety testing for new products, and nanoparticles would thus be examined under this system, albeit not specifically as nanoparticles. However, should silver nanoparticles be incorporated into socks, there would be limited scope for testing product safety from nanoparticles as nanoparticles or as part of the socks. Thus, there is much to examine in this study for the regulation of nanoparticles and nanotechnology products.

After examining many aspects related to high technology regulation, the next section goes on to synthesise these findings in the summary.

2.4. Summary

This chapter has considered various aspects of the regulation of high technology, nanotechnology and nanoparticle products. Without going too wide to engage in already well-considered areas for high technology regulation, this chapter instead focussed on findings from what I considered the most pertinent extant literature for nanotechnology, and nanoparticles within a neo-liberalist framework. While, neo-liberal regulation certainly does not negate the importance of product safety, it can mean that there is a direct conflict between stakeholders on the one hand who seek to mitigate risk, and others who wish to pursue rapid commercialisation, with minimal regulatory barriers. In practicality, this means that this arena has to be negotiated, and perhaps like other areas of life, an equal balancing act is sought but rarely obtained. It is of course rather simplistic to construct current regulatory systems as being enthralled to commercial interests, although like with any statement, it would appear that there is some minor truth here. Instead, and against a background fear of past regulatory 'failures' from products like Thalidomide, it would seem that many stakeholders are acutely aware of the risks from limited risk mitigation. Most challengingly however, is the potential to better regulate nanotechnology and nanoparticles. At present, there is 'no' specific nanotechnology regulation, and instead, conflicting discourses exist stating that nanotechnology should be specifically regulated, which is a view I share, and the opposite, whereby current regulations are constructed as being in essence fit-for-purpose to adequately capture the

phenomenon of nanotechnology. The latter view is one I disagree with on the basis of the physicality of these products. Importantly, while current data is perhaps limited for the 'real' risks from nanotechnology, I believe it to be sufficient to warrant a stronger stance towards regulating nanotechnology as a new collection of physical entities, at least where scientific data supports this claim. To expand on this more, the new chapter goes on to consider and examine nanotechnology and nanoparticles as physical entities.

Chapter 3. Nanotechnology and Nanoparticles

3.1. Introduction

This chapter is broadly driven by the research question 'What are nanotechnology and the product class of nanoparticles, from a scientific and socio-linguistic perspective?' In this chapter there is a predominant focus on nanotechnology and nanoparticles as a collection of products, in which over one thousand six hundred nanotechnology products are currently sold into a global marketplace (CPI, 2014). While introducing nanotechnology, the main focus is towards nanoparticles, which are currently at the vanguard of nanotechnology commercialisation (Huber, 2004). By examining nanotechnology as well as nanoparticles, the link between the two areas can be highlighted where appropriate, while still honing in on specific aspects for nanoparticles where appropriate. As part of this examination, a consideration is also made of the different discourses surrounding nanoparticles and nanotechnology, in which regulators must navigate to understand the physical phenomenon of these products. Alongside these aspects, commercial drivers for nanotechnology R&D and commercialisation are drawn out to contextualise the importance of nanotechnology and nanoparticles to organisations (particularly businesses). Addressing these aspects, an examination is made of the history of nanotechnology, as well of the challenge of defining nanotechnology and nanoparticles, as well as the regulation of high technology phenomena. These themes, predominantly focussed towards nanotechnology and nanoparticles, have been worked to highlight the importance of the physicality of high technology products. Against a lack of physical contextualisation often displayed from extant literature within regulatory arenas for nanotechnology and nanoparticles, this is an important contribution, particularly with a major theme of this study being risk mitigation. As a starting point, and to create a historic contextualisation, the next section considers the history of nanotechnology.

3.2. The History of Nanotechnology

The rapid growth of manufactured nanotechnology products is a relatively recent phenomenon. The creation of natural nanoscale entities has however existed for millennia, but with the focus of this study being on the 'man made' materials. Nanotechnology has an origin based on the talk delivered by the physicist Richard Feynman (1959) called '*There's Plenty of Room at the Bottom*'. Although Feynman did not use the term nanotechnology at this point, the suggestion of nanoscale phenomena and potential products was given. From this inceptive discourse, it took until 1974 for the term 'nano-technology' to be used by Norio Taniguchi, and until 1986 for the term nanotechnology to be popularised by Eric Drexler's book, '*Engines of Creation*'. Advances in nanotechnology have arguably been techno-scientific in nature (Pirani and Varga, 2008), where technical and scientific advances have jointly driven product advances (Kroto *et al*, 1985). Social contextualisation of these advances has been through a variety of cultural sources, such as the media, television, novels and commercial and legal discourse (Davies, 2011).

While there is the potential to view nanotechnology as an entirely 'new' collection of small products, this is an overly simplistic view. It certainly is the case that nanotechnology products can be viewed with current advanced instrumentation. However, before advanced instrumentation existed, nanotechnology products were often created as part of larger materials, but without the knowledge on the part of the manufacturer that these small-scale products existed. Put simply these constituent parts and materials were just too small to 'see' and were part of larger scale materials. As an example, the oldest known example of nanomaterials usage is with nanoparticles in the Lycurgus Chalice (shown in Figure 3.1), which was made in the fourth century AD, currently held at the British Museum.

Lycurgus cup with diffused light

Lycurgus cup with focussed light

Figure 3.1. The Lycurgus Chalice (The Trustees of the British Museum, 2013)

The Lycurgus Cup is an exemplar of products created without the explicit knowledge of nanoscale phenomena, but with the knowledge that some materials created physical properties of interest. Thus, the image of the Spartan lawmaker Lycurgus is embedded with nanoparticles, which produce enhanced colours from within the glass. When light is reflected from it, the glass appears green but when light is shone through it, the glass appears red. This colour change has been attributed to the gold, silver and copper nanoparticles that are dispersed in the glass. Importantly, in the pre-nanotechnology era, bulk scale materials were known to create desired effects, but knowledge of the nanoscale functionality was unknown.

Looking at other examples of nanoparticles used throughout the pre-nanotechnology era, the phenomenon can be found in ninth century AD pottery from the Mesopotamian era (Leonhardt, 2007). In these products, nanoparticles were used in the glaze on ceramic pottery (again without the explicit knowledge that these small scale entities existed). Such techniques were brought to Spain in medieval times, as Arabian culture spread, where it migrated to Italy, for use in Renaissance pottery (CPD, 2004). Stained glass windows are another example of nanoparticle incorporation into glass to enhance the perceived visual effect of a material. While it may appear that the use of nanomaterials prior to the

nanotechnology era was limited to aesthetic appeal, this is not necessarily the case, as the use of carbon nanotubes (CNTs) were incorporated into Arabian swords to increase their strength (Reibold, 2006). From such simple beginnings, and as awareness of nanomaterials increased, and the desire to use them knowingly, so did the need for regulation, and rationales for regulation.

To further understand the phenomena of nanotechnology and nanoparticles, and the mirror of language with the physicality of these entities with discourse, the following section considers defining nanotechnology and nanoparticles.

3.3. Defining Nanotechnology and Nanoparticles

Constructing useful and workable definitions is no small challenge and raises many challenges, for what is sought from this endeavour. Perhaps most simplistically, the creation of a 'dictionary' definition is that it creates a signpost that others can follow to share meaning, and to engage with the physical and social world through. While definitions can be useful, when constructed 'poorly' without clear demarcation points, confusion can reign, where meaning is not easily shared, and in effect reduces the value of the definition. With these aspects in mind, this section has sought to understand the construction and potential use of definitions of nanotechnology and nanoparticles, and how different stakeholders use them.

To understand nanotechnology and nanoparticles, much discourse has focussed on defining nanotechnology by 'breaking' these words into their root parts (Hull and Bowman, 2010). For example, nanotechnology is composed of two components, including '*nano'* and '*technology*' and nanoparticle, into '*nano*' and 'particle'. The prefix nano is derived from the Greek word '*nanos'* meaning *'dwarf'* and in scientific arenas is commonly used to refer to a material with at least one dimension between 100 million times and one billion times smaller than a metre ($\times 10^{-7}$ to $\times 10^{-9}$), although for nanoparticles, all three dimensions are argued as needing to be within this scale. Examples of nanotechnology and

nanoparticle definitions are shown in Table 3.1 and Table 3.2 and highlight size as a predominant factor of definition.

Number	Definitions of Nanotechnology
1	Nanotechnology is the creation of functional materials, devices and systems through control of matter on the nanometer length scale (1-100 nm), and exploitation of novel phenomena and properties (physical, chemical, biological, mechanical, electrical…) at that length scale (CIRS, 2013)
2	The branch of engineering that deals with things smaller than 100 nm (especially with the manipulation of individual molecules) (hyperdictionary.com, 2015).
3	The development and use of devices that have a size of only a few nanometres (Physics.about.com, 2015).
4	The study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale (Royal Society of London, 2015).
6	Nanotechnology is the understanding and control of matter at dimensions of roughly 1-100 nm, where unique phenomena enable novel applications (National Nanotechnology Initiative (NNI), 2015).
7	'*Matter at dimensions between approximately 1 and 100 nanometers*' (Drexler, 2015).

Table 3.1 Definitions of Nanotechnology.

Examining the definitions shown in Table 3.1, there is a predominant focus on constructing nanotechnology as a size related phenomenon, no doubt linking these definitions to scientific constructions, which is shown when references are examined. Coupled with this is the often-framed requirement for materials or products to be related to an application potentially through commercial usage, with a frequent push that nanotechnology is by nature a scientific endeavour. These aspects are also predominantly found for nanoparticles, but with a requirement that 'all' three dimensions are between 1 and 100 nm, as shown in Table 3.2.

Number	Definitions of Nanoparticles
1	Ultrafine unit with dimensions measured in nanometers - billionths of a metre (Brittanica.com, 2015).
2	A particle spanning 1-100 nm (diameter) (ISO (Wiley, 2013).
3	An ultrafine particle whose length in 2 or 3 places is 1-100 nm (ASTM (Wiley, 2013).
4	At least one side is in the nanoscale range (SCCP (Wiley, 2013)).
5	A particle with diameter between 1 and 100 nm, or a fibre spanning the range 1-100 nm (NIOSH (Wiley, 2013).
6	All the fields or diameters are in the nanoscale range (BSI (Wiley, 2013).

Table 3.2 Definitions of Nanoparticles.

As can be observed from Table 3.1 and Table 3.2 definitions of nanotechnology and nanoparticles often vary, which as argued by Fleischer, Jahnel and Seitz (2010) has in turn created numerous challenges for meaningful legal engagement with nanotechnology based on unclear definitions and meanings. Importantly, the word nano does not have any legal definition attached to it and there are arguments about the lexical (dictionary) definition. Coupled with multiple legal, scientific and social constructions of nano, much confusion has been created. Even though there is variation, attempts to draw on etymological meaning have also been confusing, as nano coming from 'nanos' means dwarf. At some level it is helpful to conclude it probably means something small or short, but any attempt to construct the phenomenon of nano to human size is ultimately unhelpful and misleading. More sense can be made if nano is linked to scientific size, which is predominantly the case in scientific discourse, but unfortunately is still linked to the word nanos as dwarf. The dwarf aspect should be dropped as adding no clearer understanding to the physical phenomena of nanotechnology and nanoparticles.

Looking beyond the use of nano with nanotechnology and nanoparticles, it is interesting to note that the word technology has received much attention, but particle(s) very little. It is unclear why this is the case, but might be that nanotechnology is assumed to subsume nanoparticles, so if the technological definition of nanotechnology is determined, this can be extrapolated to

nanoparticles? To gain further understanding, it is worth looking at attempts to define technology, which can also often vary depending on the discipline, application or research paradigm. For example Glen (2014) utilised an etymological basis for technology by examining the root Greek words of *techne* and *logia* to mean, '*art, skill, cunning of hand*' and the use of this art to solve a problem, respectively. Importantly, this approach has found much favour in academic discourse regarding this area, and suggests that technology is a process for making products. Thus nanoparticles are products with all three dimensions at the nanoscale, and more detailed consideration of a nanoparticle is not perceived as particularly relevant for a definition. As is shown in Section 2.4, this is misleading for the physicality of nanoparticles.

The aspects of definition are pivotal for understanding nanotechnology and nanoparticles, particularly in legal discourse, where scientific constructions of these products are utilised to inform legal decision-making. A greater exploration of the challenge of definition is therefore considered in the following section.

3.3.1. The Challenge of Definition

The creation and use of definitions can be helpful for creating common meaning about all phenomena, with the need and challenges for achieving clarity of meaning arguably being even greater for high technology products. Definitions, thus act as language-based symbolic representations of reality, where demarcation points are drawn around phenomena to create shared meaning (Harris, 2003: 2007). Common understanding for nanotechnology through definition is important, as in comparison to many other disciplines, law more overtly relies on the possibility of determining discursive meanings, resulting in definitions becoming an important part of modern jurisprudence (Harris, 2007). While there has been much discourse regarding the use and production of definitions by law, arguably all definitions are 'wrong' but some are useful, and some certainly more useful than others. In other words, no definition can truly capture any part of the physical world, but it can capture enough as in the example of nanotechnology to be useful and aid in shared meaning and legal

discourse. At worst, definitions may fail to capture physical phenomena drawing poor demarcation points and misconstructing the physical world that hinders legal discourse and shared meaning.

There are two main types of definition, which are the stipulative and common (lexical), with Mill (1884: 1) stating for both that:

> '*The simplest and most correct notion of a Definition is, a proposition declaratory of the meaning of a word; namely, either the meaning which it bears in common acceptation, or that which the speaker or writer, for the particular purposes of his discourse, intends to annex it*'.

What Mill describes, as 'common' use is the 'lexical' definition, and can be considered a culturally relevant shared meaning from a certain point in time (Robinson, 1954: 35). Without getting drawn too deeply into linguistic debate, the common or '*lexical definition is used to report the meaning that a word already has in language*' (Hurley, 1988: 82). Stipulative definitions however are communicated and potentially explained before their contextual use. When considering the two approaches to definition, the questions can be asked, which should be selected? And why? For clarity and making sense of definitions, a common meaning should be used, unless there are reasons to move towards a stipulative definition. Looking at technical, scientific and legal definitions, they too should follow this rule. Importantly, it might appear that technical, scientific and legal areas are not common and thus should be considered stipulative, but this is not so. Commonality is only required inasmuch as it is common to a group of users, such as lawyers, or scientists. Thus new definitions can be created and enter common meaning, although it must be recognised that no claim is made to the way that individuals engage with common definitions, which can vary.

Arguably the creation and use of any definition should be approached with linguistic reflexivity and an awareness of what has gone before, where shadows from other terms and definitions may be cast over what is currently being used. If this is not fully considered, misconstructions of physical reality may occur,

leading to unintended links to other words, meanings and definitions. Definitions for high technology products have suffered from this aspect, whereby individuals creating names and definitions have sought to capture the physical essence of the phenomenon being named. Nanotechnology is an exemplar of this approach, which has brought much linguistic ambiguity to understanding what is meant by the name. Unfortunately the linguistic sign (the name) of nanotechnology is not arbitrary and as such carries linguistic 'artefacts' creating a shadow for which the newly constructed definition operates within. Harris (2007: 18) commented on this aspect:

> '*A word does not mean what it does because there is some hidden principle determining what meaning that particular sequence of sounds or letters must have. In principle, any form might have any meaning, and any meaning be expressed by any form*'.

To be able to communicate meaning in a common way, even between 'experts' requires that a linguistic sign used be not unduly influenced by prior historic constructions. Nanotechnology suffers from this, which has led to much confusion over what nanotechnology means, not only within law, but science and the wider social world. This has arguably resulted in a lack of consensus over what is meant by nanotechnology. According to Brazell, (2012: 2) the term is *'ill – suited to the subject matter, while major uncertainties remain even as to the scientific understanding of the subject.*' While there will always be challenges in the ability to use language to fully capture complex and opaque physical phenomena, there is as Wittgenstein (1961: 13) argued, a '*requirement that simple signs be possible* [and] *the requirement that signs be determinate*' to enable individuals to assume '*how things are*'. For law, there is a requirement that words and definitions be usable for arguably not only individuals and organisations within the field of law, but also for others outside of law who will seek clarity over meaning. As an example of this and drawing on the area of intellectual property (IP) law, if meaning is unclear, the patent holder *'may have to live with the uncertainty as to whether someone will dispute their claim at some point down the road'* (Berger, 2007 [posted in Nanowerk May 11th]). Importantly, with nanoparticles existing within the shade of nanotechnology, any

uncertainty with nanotechnology is potentially reflected onto the phenomenon of nanoparticles. To more fully explore wider constructions of the phenomenon of nanotechnology, and potential challenges for law, the following section considers wider socio-linguistic constructions of nanotechnology.

3.3.2. Socio–Linguistic Constructions

The confusion surrounding nanotechnology has in part been a consequence of the variety of common, scientific, and social meanings, which as argued by Boholm and Boholm (2012: 16) extend beyond a scientific definition of size, and has included the following constructions:

> '[1] *Very small X, where X is an object that is small, for example, nanocar, an activity that is short, for example, nanosemester, or an activity involving small objects, for example nanoblog. In none of these cases is the relevant scale of description that of nano in the technical sense of billionth part;*
> [2] *Nanometre-sized X, where X is an object for example nanoparticle;*
> [3] *X operating at nanoscale, where X is an activity, process or agent, for example, nanoscience, nanoanalysis and nanoresearcher; and*
> [4] *Nanotechnological X, where X is an object resulting from some activity operating at the nanoscale but not necessarily itself nanometre sized. For example, nanoclothes – which can often mean both nanometre sized and nanotechnological (containing for instance nanotubes)*'.

This example suggests that nano as a prefix or stand-alone word can mean a variety of different things in different social groups and disciplines and while it may predominantly mean small, does not necessarily have to be between one billion and one hundred million times smaller than a metre. It is not just the word nano that can be viewed in a wider socio-linguistic sense but also the word technology. As a brief example, while technology can be seen to be ushering in a

silver bullet to heal societal ills, it has also been perceived as unnatural, potentially catastrophic and generally damaging to mankind (Fischhoff *et al*, 1978; Slovic, 1987, 1992). Negative views of nanotechnology have been affected for example by religious beliefs (Ho *et al*, 2010), which resulted in a lack of acceptance and even resistance to emerging technologies (Gaskell *et al*, 2004; Nisbet, 2005; Ho *et al*, 2008; Brossard *et al*, 2009).

There have been a number of media studies that have described the concepts of nanotechnology, with varying opinions being put forward (Dudo *et al*, 2011). It is important to consider that extant studies highlight both positive and negative aspects of nanotechnology, with different social sources producing different opinions, and for example the natural sciences predominantly being positive (Kjølberg, 2009). If Europe as a whole is considered and compared to the USA, newspaper reporting in the USA has focussed on positive aspects, whilst Europe has shown a higher level of concern about potential negative affects of nanotechnology on society (Friedman and Egolf, 2005).

Through discourse produced from the media and academic disciplines the discussion amongst different stakeholder groups including the discipline of law has increased (Simons *et al*, 2009). However, studies and opinion surveys have shown that while non-scientist familiarity of the term nanotechnology is increasing, the overall level of understanding and awareness of what nanotechnology is and its risks is still low (Schütz and Wiedemann, 2008; Simons *et al*, 2009; Priest *et al*, 2010). Problematically, ideas about what nanotechnology is, is within a sea of discourse produced from various cultural sources such as various science fiction (literary and film), and often as a vehicle to promote the harm that can be produced from the use of this technology. Examples of this include Dean Koontz's (2003) book *By the Light of the Moon*, which tells a story about nanomachines that devours humans. This can be coupled with terms such as 'grey goo' (Ball, 2003), which has become somewhat culturally embedded as the perceived consequence of poorly controlled and regulated nanotechnology i.e. all life is reduced to grey goo. Alternatively, nanotechnology has been promoted as a medical panacea, in productions such as the BBC series 'Red Dwarf.' It is thus important to acknowledge that knowledge

held by individuals is not scientifically 'pure', with wider social constructions having influenced the formation and use of knowledge held.

The variety of socio-linguistic constructions of nanotechnology has the potential to create confusion for shared meaning for what nanotechnology is (although this is not to suggest that a singular view has to exist, but more a commonly and scientifically accepted view is dominant). For example and drawing on the thoughts of Berger (2007: 2) the variety of constructions potentially creates *'a sure recipe for conflicting terminology and a dispute over what is meant and intended'*. The following section on a positive and negative nanotechnology discourse focuses on the challenges within scientific and technological arenas for producing clarity.

3.3.3. Positive and Negative Discourses

Nanotechnology exists in an ever-changing sea of discourse, and under a simple view can be segmented into positive and negative persuasive 'promises' that may be delivered. Importantly, there have been numerous promises made about nanotechnology, which impact on the way that nanotechnology is discussed, scientifically tested and casts a discursive shadow within which law must operate. With nanotechnology products entering and currently being sold into the marketplace, the issue of the promises of nanotechnology being used to fuel perceptions of these products, particularly as being the 'same' as bulk scale larger products, cannot simply be ignored. This section critically engages with the different lenses through which nanotechnology can be viewed, by looking at examples of products that are already within the marketplace from a discursive perspective. It is worth reiterating an earlier premise that although blunt segmentations of positive and negative discourses have been used for simplicity, in practicality, discursive life is rarely this simple, and as nanotechnology discourse is engaged with, this should be remembered.

Discourse is the vehicle for the way in which legal actors interact and construct meaning with the social and physical world of nanotechnology. Through

discursive framing, discourses from the natural sciences and social spheres echo into the arena of law, where it is reconstructed. Using a reductionist approach to discourse enables its segmentation into three areas including micro, meso and macro, where all may influence each other. In many ways it is pertinent to regard the three segments as entangled with each other, and with it not always being possible to isolate the effect of the different segmentations from each another. An example of this is perhaps most clearly observed from macro discourse such as the use of certain narratives to promote nanotechnology. In this chapter, it is the promotion of nanotechnology as a vehicle towards societal good and bad, particularly with regard to law that is of interest. This is perceived as important due to the high use of language to promote nanotechnology, and the difficulty of finding discourse about nanotechnology that does not sit under the shadow of this promotion, even within law. The extensive claims made about nanotechnology are not the direct focus of this study, but more the interaction with law. It is important to recognise the discourse-laden system prevalent for promoting nanotechnology, particularly for claims for whether it will bring economic and health benefits, or alternatively the next cataclysm. Table 3.3 gives a brief examination of this aspect, by showing some prevalent linguistic vehicles to promote nanotechnology as 'good' and bad 'products'. Although criticisms can be made about linguistic 'short-cutting' through the use of language-based vehicles, it is important to recognise that where complex, opaque and ambiguous phenomena exist, this discursive stance can enable an easier view to be made (Weick, 1995). As might be expected, there is a continuous balancing act between simplification and constructions from law and science, and where ultimately discourses must be navigated and negotiated so that stakeholders can make sense of what is being said.

Linguistic Vehicle	Quotation	Promoting
Meta-narrative	'*Nanotechnology is a technology which has a huge potential in the development of health technologies and medical treatment'* (McHale, 2008: 377).	Medical and Health Benefits. Framed as good.
Scientism	'*Nanotechnology is regarded as a new kind of science, in which considerable hope and promise is invested on the basis of predicted applications*' (Macnaghten, Kearnes and Wynne, 2007: 132).	A new technological future of certainty and a countering of public mistrust in science. Framed as good.
Metaphor	Nanoparticles as '*Small robots, nanobots or micro machines*' (Eyck and Hernandez, 2009: 10).	Nanotechnology as intelligent. If the 'grey goo' scenario is considered it is bad.
Story-telling	'*In the medical context, the use of this technology was facilitated by the scanning tunnelling microscope which enabled scientists not only to see atoms but also painstakingly to move them around*' (McHale, 2008: 377).	High technology manipulation of physical matter is framed as good, thus nanotechnology is good.

Table 3.3. Overt Linguistic Themes Promoting Nanotechnology

While demonstrating some of the linguistic vehicles used to promote nanotechnology, it must be acknowledged that nanotechnology is increasing in importance in the global economy and in the number of individuals employed in this area (ETUC, 2008). The number of commercialised products available for sale within business-to-business (B2B) and business-to-consumer (B2C) is also expected to grow, further adding to the need for more understood regulation and governance. Unfortunately there is the argument I would make that the examples in Table 3.3 are distortive in nature particularly for the physicality of nanotechnology, which often functions differently in comparison to the linguistic vehicles. With such distortive discourse, poorly capturing the physicality of nanotechnology products, it is worth raising questions of what is law engaging with? As surely as shown in these examples, it is not the physical existence of

nanotechnology. To expand the discussion on the physicality of nanotechnology, the next section explores scientific/technological constructions.

3.3.4. Scientific/Technological Constructions

The lens used within scientific and technological constructions of nanotechnology predominantly frame nanotechnology as small products. Under this simple view, all nanotechnology products must have at least one of their three physical dimensions smaller than one hundred nanometres. Conceptually, a human hair has a diameter one thousand times larger than the upper limit for the nanoscale (Engelmann, 2011). At the bottom end of the nanoscale (Watson and Crick, 1953), the nanoscale is depicted within Figure 3.2, relating it to the atomic scale (below the nanoscale) and the macro/bulk scale (above the nanoscale):

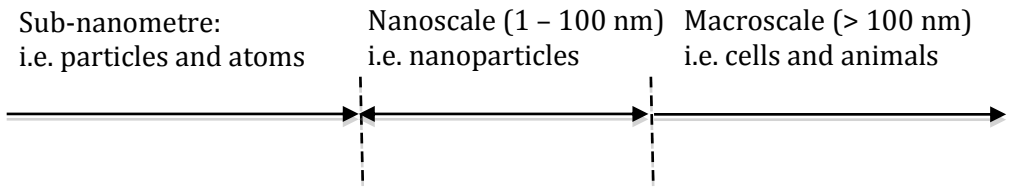

Figure 3.2. Diagrammatic representation of the nanoscale. This figure depicts how the nanoscale fits in with smaller and larger units of measure (Dean, 2014).

Nanotechnology products are thus very small, and it can be difficult to conceptualise just how small, and what exactly the size-defined regime of one to one hundred nanometres really means. This challenge arguably echoes throughout the legal, commercial and scientific arenas as multiple individuals and organisations try to come to grips with the reality of size-related products, at a scale rarely dealt with. Putting this a different way, products have rarely been defined by size at this scale, at least in a way pivotal to their labelling. An example of this is a hypothetical virus, which is fifty nanometres in diameter and sitting firmly within the nanoscale region, yet receiving virtually no scientific or legal discourse about the size, with functionality being preferred.

Creating understanding at the nanoscale can become difficult, as while it can be argued that nanotechnological entities exist between one and one hundred nanometres (ISO, 2008), creating upper and lower size limits, other definitions such as by SCENIHR (2007b) argue that nanoscale entities have dimensions less than one hundred nanometres, and are silent on a lower size limit. SCENIHR (2007b) is more ambiguous by remaining silent on a lower size limit for what can be considered nanoscale. Likewise the ISO (2008) definition is also problematic, as it appears to suggest that all three dimensions should be within the nanoscale size range of one to one hundred nanometres, which under this blunt view would mean that only nanoparticles are nanoscale. To explore this aspect further, the three main categories of nanotechnology products are shown in Table 3.4.

Nanoscale Dimensions	Common Name	Description
1	Nanowires and nanotubes	Carbon-based, single atom and cylindrically shaped.
2	Thin-films	Thin nanoscale sheets.
3	Nanoparticles	Often constructed as spheroidal shapes which although have all three dimensions within the nanoscale are confusingly described as zero-dimension.

Table 3.4. Dimensional Segmentations of Nanomaterials (Bala, 2014).

Looking at Table 3.4 there are three main classes products/materials/entities constructed within the arena of nanotechnology. Unfortunately, the consideration of nanotechnology definitions has shown limited interest in engaging with these three distinct segmentations of products found within this area. This is a problem, as when the physicality of nanotechnology is considered, all products exist with dimensions in *x-y-z* axes, with this aspect not being discussed. Simple definitional constructions of being less than one hundred nanometres are unhelpful as it presupposes a level of technical knowledge to apply this definition. For example nanoparticles have all three dimensions less than one

hundred nanometres, but a thin-film may only have one dimension in this size, with the other two dimensions being up to metre scale or larger.

Moving on to look more at the physicality of nanoparticles as a physical phenomenon, this aspect is considered in the following section, to create a platform of knowledge, to support an understanding of their use in commercial settings, which will facilitate a deeper knowledge of the challenges faced by law in such instances.

3.4. Nanoparticles as a Physical Phenomenon

Nanoparticles have received a growing interest from numerous stakeholder groups, including organisations, companies, and governments etc. Interest has not just focussed on commercial exploitation but how to regulate this collection of activities, and has included entities such as REACH (Registration, Evaluation, Authorisation and restriction of CHemicals), EPA (US Environmental Protection Agency), NIOSH National Institute of Occupational Safety and Health), ENPRA (Risk Assessment of Engineered Nanoparticles) and IOM (Institute of Occupational Medicine). I believe that central to any engagement from any legal entity is an understanding that nanoparticles are small clusters of atoms within a size range between one billion and one hundred million times smaller than a metre for each nanoparticle. It is of course recognised that wider socio-linguistic constructions also exist, but where possible they should be acknowledged and perceptually bracketed, to enable a more scientifically orientated lens to be used.

Although singularly small, nanoparticle products can contain millions or billions of nanoparticles per product, and can display unique and novel characteristics, offering new product potentials. Within any product, it is also possible that nanoparticles will be trapped within a solid or gel, or free to move about in a liquid of gaseous form. All may have different implications for how stable nanoparticles are, how safe they are, and if they change their size and shape, whether they change their toxicity. Figure 3.3 shows different nanoparticles with varying sizes and shapes.

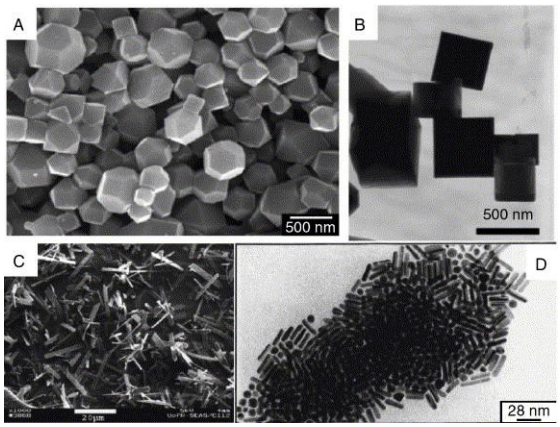

Figure 3.3. Nanoparticle images – showing different sizes and shapes (Eastoe, Hollamby and Hudson, 2006: 10). In this study, nm refers to nanometres.

As can be seen in Figure 3.3, there are a variety of physicalities of nanoparticles, and it must not be assumed that nanoparticles are all the same. This is perhaps one of the big challenges for law, which is how to engage with a product that contains millions of smaller entities, each with a potentially different functional activity. Using a hypothetical example, one nanoparticle in the product causes cancer, and another cures it. This is arguably a new challenge for law, which has never had to deal with this physical variety of functionalities within a product before. More than this though, and as will be explored in the following section 3.4.1. 'Nanoparticle Stability and Ostwald's Ripening' the physical shape of nanoparticles may change, alongside their physical activities with other entities, such as humans, which presents further challenges for engaging with these products.

Utilising a scientific lens, the physical characteristics of nanoparticles such as size, shape and chemical composition etc. are pivotal. Using this lens, and examining size first, nanoparticles are a material class with all three dimensions between one million and one billion times smaller than a metre per nanoparticle (El-Shall and Edelstein, 1996). Compositionally, nanoparticles can be inorganic (metals), organic (carbon-based) or a combination of both, with it being possible to produce nanoparticles through scientifically and engineering based biological, chemical or physical processes. They can either be in the solid, liquid or gaseous state, which means that although a nanoparticle is less than one hundred nanometres in all three dimensions, the product may well be larger. This is

particularly the case where nanoparticles are incorporated into larger scale products such as deodorants, drinks, bandages etc. with these aspects being more fully considered in the following chapters.

To understand nanoparticle properties, it is important to understand the physical characteristics, which are split into the three dimensional features related to their *x-y-z* axes, as well as the crystal structure (atomic arrangement within the three axes). Perhaps not surprisingly, the ability to measure these features has increased with advancements of scientific understanding and capabilities of more advanced equipment. Many measurements however, still require high-levels of scientific expertise, have high-costs with laborious measurement routines, meaning there is no quick route to product knowledge. Problematically, and when measuring nanoparticles for their physical characteristics, it cannot be assumed that one nanoparticle is necessarily the same as the next, resulting in statistical distributions of different parameters. Part of the difficulty is that within any sample of nanoparticles, *x* percent may cause cancer, where *y* percent will not. Determining the nanoparticle characteristics that are harmful or in a different example can be hugely problematic, resulting in statistical techniques to correlate averaged data with health and safety or beneficial data (personal communication with Dean, 2011). This is a challenge for law, as parts of any sample may for example be toxic to humans, with current tests not being routinely carried out with prolonged exposure to the phenomenon. This aspect will be considered in greater detail, later in this study in section 5.3.2. More than this though has been an assumption within science and law that nanoparticles are a predominantly static collection of products and physical entities, when they are often not. The next section on nanoparticle stability and Ostwald Ripening therefore explores this in more detail.

3.4.1. Nanoparticle Stability and Ostwald Ripening

Within studies examining nanoparticle law there has been a propensity to regard nanoparticles as stable and physically static products. This is not to say that there has not been much debate and scholarship about nanoparticles interacting with biological entities (Domingo-Espin *et al*, 2011) or the wider environment (Yon and Lead, 2008) but more that irrespective of these interactions, nanoparticles themselves tend not to change. While it is acknowledged that viewing nanoparticles as static products provides a simpler view of physical reality, it is not one that should go unchallenged. As a brief starting point, nanoparticles have the potential to either dissolve into smaller non-nanoscale molecular constituents or aggregate into larger non-nanoscale structures, which confronts the notion that it is always nanoscale products that are being discussed or regulated within law. This process known as Ostwald Ripening (Ostwald, 1896, 1897) occurs in a solvent (liquid surrounding the nanoparticles). This is where the distribution of mean particle size increases as a result of smaller nanoparticles dissolving and larger nanoparticles growing (Liu *et al*, 2007). According to Binion (2008: 19), '*Nanoparticles display a lot of bizarre qualities and we still don't know anything about the long term affects of these particles if they have accumulated in the body or conglomerated into larger particles*'. This can be even more problematic where nanoparticles are changing size and morphology but this is not being recognised or captured within regulatory systems.

While it may appear that such discussions are more fitting for the natural sciences, I argue that since size is used as a main demarcation point for whether a product is nanoscale and within the arena of nanotechnology, law must engage with this aspect as well. The question of course becomes, how should law do so? And what might it achieve? These points are discussed throughout this study where perceived pertinent, but as a starting point, a closer look at the physicality of the production of nanoparticles is considered.

The production of nanoparticles by all manufacturing processes results in a distribution in size and morphology of nanoparticles, with different results being observed depending on the techniques and materials used for production (Dana,

2012). Law has showed little interest in this area, and to reiterate has predominantly taken a stance that nanoparticles within any product are 'pretty much the same'. At some level I would argue that this is a consequence from the natural sciences, where and potentially for ease, this issue is not particularly discussed, with a preferred view that product size and shape does not change. An engagement with the physicality and complexity of this aspect does not have to be an overly problematic issue for regulation, which from a regulatory perspective has many methods to 'deal' with this challenge. At present though and as explored in the following section, a paucity of scientific data is arguably holding back any real potential to understand the physicality of nanoparticles and nanotechnology.

3.4.2. Paucity of Scientific Data

With so much discourse focussing on nanotechnology and nanoparticles, it is perhaps most surprising that there has in actuality been very little scientific testing of nanoscale products for aspects such as safety in a 'real world' environment (Yon and Lead, 2008). Caution must be taken when examining this comment, as it is not that that there has not been scientific testing of nanoscale phenomena, but more that much testing has been carried out for phenomena observed in laboratories, which may not necessarily correlate to how products will behave in a 'real world environment.' More simply, while much examination of nanoscience is on going, and for example within university laboratories, this is often focussed on nanoscience as opposed to nanotechnology products. This is not just a university issue, but also more one where there is often a predominant examination of 'simpler' science, which is cheaper, easier and faster to carry out than for complex products.

Using a hypothetical example of silver nanoparticles. It is in principle relatively straightforward to measure the size distribution of silver nanoparticles and how stable they are, 'as themselves' in water, providing that there is access to equipment, knowledge to carry out the test, and interpret and resource to do so. This information can be invaluable for nanoparticles in a 'naked' state and where

there is little else to influence the testing. However and more problematic is any requirement to move to a more complex system, where for example the same silver nanoparticles are put into a silver bandage or into a more complex mixture. Examining the bandage scenario first, there is no reason to assume that the silver nanoparticles will remain the same size and shape if incorporated into a bandage. This means that the toxicity and efficacy can change and may continue to do so with exposure to different environmental conditions. This leads to the question, of what an initial test of size distribution and stability was meant to show? It is unlikely to mirror how the product will perform in a 'real world' setting. Moving onto look at a more complex liquid solution, with added silver nanoparticles, measuring the nanoparticles may well become much harder with other constituents present potentially masking the size and stability of the nanoparticles.

Fundamental to the challenge of collecting data is the ability to produce results that are meaningful for application as nanotechnology and nanoparticle products. When nanoparticles are added to other liquids, solids or gases, there is a great potential for their physical features to change, so even if they have been shown to be safe before the addition, it cannot be assumed they will still be safe after the addition. This raises an important question about whether current regulatory systems might be able to address and capture this aspect. Reiterating Chapter 2 Section 2.2.4, there is no specific requirement to assess nanoparticles as separate entities under current regulatory frameworks. In practicality, this means that there is very little incentive for product manufacturers to engage in assessing nanoparticle aspects such as size, shape, toxicity etc. and certainly no recording mechanism stipulated. Of course, depending on the product sector and application, aspects such as toxicity may well be assessed, as part of a product, but with virtually no capability of stating for example '*nanoparticles with a cuboidal shape, and x nanometres in diameter increase the likelihood of y pathogenic state*'. Thus this study is setup against a paucity of data, where not only is there a lack of incentive to carry out more fit-for-purpose testing, but an arguable lack of operators and equipment to do so.

Drawing all of the aspects discussed so far in this chapter together, the next section produces an over viewing summary.

3.5. Summary

This chapter has highlighted that nanotechnology is a pervasive collection of technology products, with nanoparticles having penetrated numerous commercial sectors. Physically, nanoparticles are generally considered as having all three physical dimensions below one hundred nm and above one nm, but with many shapes and crystal structures being displayed by different products. Even within the one to one hundred nm size range, there is a potential of a ninety nine nm size difference for each of the three dimensions. All of these factors can result in different physical properties, which can be desirable but also negatively perceived. Beyond the scientific construction of nanoparticles there are often good and bad 'stories' promoted for nanoparticle products, which can further complicate discourses for the regulation of nanoparticle products.

At present, there has been a predominant regulatory stance to classify nanomaterials as being the same as their bulk (above nano-size) 'equivalents'. This is a problematic approach as for example; a silver nanoparticle could in principle be regarded as having the same health and safety concerns as a silver microparticle (one thousand nm) or much larger material (above one thousand nm) or a much larger structure (i.e. two metres). Clearly the toxicity of these differently sized silver entities cannot be the same, but are often regarded so from the current regulatory perspective, and is perhaps a consequence of no specific nanotechnology regulation. Thus simplicity is attained, but is at the expense of a system that in many ways poorly captures the physicality of these materials.

It is of course relatively easy to be drawn into arguments, which overly simplify the phenomena of nanoparticles and nanotechnology, and how and why (if at all) they should be regulated. Competing social, commercial, environmental and legal drivers all potentially compete with different views being espoused for how

to regulate nanotechnology. With this in mind and following on from the comments raised in this section about the safety of nanoparticle products, the following chapter considers the commercial world of nanotechnology and nanoparticles.

Chapter 4. The Commercial use of Nanotechnology and Nanoparticles

4.1. Introduction

This chapter is broadly driven by the research question, 'How are nanotechnology and nanoproducts used commercially, and what are the perceived negative and positive attributes potentially influencing their regulation?' In this chapter, how nanotechnology can be used in commercialised products for the benefit of society is examined with two main areas, including the commercial world of nanotechnology and the application of nanoparticles being addressed. While nanotechnology is used in a wide variety of products, it is not feasible to cover all areas, and instead three main areas of food, medicine, and cosmetics, have been chosen as exemplars. These areas were chosen as areas where much discourse has been produced from multiple disciplines including science and law. As such these areas are more amenable for study based on current discourses. The attraction for businesses and consumers to use nanotechnology are examined throughout this section. For example persuasive elements from these areas include promising treatments for illnesses that conventional medicine cannot fulfil, food in areas where there is poor soil and cosmetics that can aid in age prevention on the skin. As a starting point, the next section examines the commercial world of nanotechnology.

4.2. The Commercial World of Nanotechnology

Over the past decades, advancements in science and technology have facilitated and enabled the creation of nanotechnology materials, which have been used as products and have generated great interest from numerous commercial sectors. This has resulted in the accelerated intentional creation and use of nanotechnology-based materials as products. While, this intentional creation has enabled a greater variety of products and commercial applications it has in part been driven by a convergence of the sciences and engineering towards the

production of nanotechnology products, with biology, chemistry and physics producing a wide range of materials. This has allowed new products to be used in areas such as medicine, environmental technology, electronics and the material sciences, while creating numerous challenges for law to engage with via these advances through regulation. In many ways, commercial nanotechnology has only been realised by the development of equipment allowing the production and measurement of nanoscale materials, allowing scientists to relate nanoscale structure to their function (Gray, 2012). Before a more in depth focus is made towards nanotechnology and nanoparticles, a background to product commercialisation is laid out in the following section, to construct a backdrop contextualisation for technology products.

4.2.1. Product Commercialisation

Scientific product commercialisation arguably starts with an inception stage, with products being driven through R&D into commercialisation. Conceptually, there are two types of market strategies that are broadly recognised for new technology products (Nemet, 2009): market pull (Schmookler, 1966) and technology push (Schumpeter, 1939). Market pull strategies are focused towards market and customer needs where there is 'opportunity recognition' (Schmookler, 1966), and is based on the concept that companies find and exploit perceived market opportunities (Kirzner, 1979). Technology push strategies are based on the idea that innovations are pushed through R&D, into sales and into the market, without a proper consideration of whether it satisfies a current user need (Martin, 1994). Wonglimpiyarat and Yuberk (2005) have argued that these two market strategies are the driving force in the process of innovation and commercialisation. Technology push has been perceived as being greater during the initial stage of technology adoption; with market pull increasing as technology push decreases (Mowery and Rosenberg, 1979). While there are multiple business models (Lux Research Inc, 2004) for R&D and commercialisation, there are numerous business and legal aspects that interact and influence the R&D and commercialisation stages, such as regulatory requirements to determine for example product toxicity for nanoparticle

cosmetics (Lux Research Inc, 2004). Other business processes such as marketing and sales are beyond the remit of this research.

With any technology is the potential to draw out the reasons for constructed business drivers, including why certain products are put through R&D and commercialised. As might be expected, there are many drivers for commercialisation including, development of novel intellectual property (IP) (Correa, 2000), novel product functionality (Institute of Medicine, 2009) meeting consumer demand (Scrinis *et al*, 2007) and generating return-on-investment (ROI) etc. As an example of customer demand for novel functionality, in the defence sector (Crow and Sarewitz, 2001: 83) stated:

> '*Nanotechnology offers a dizzying range of potential benefits for military application. Recent history suggests that some of the earliest applications of nanotechnologies will come in the military realm, where specific needs are well articulated and a customer – The Department of Defence already exists.*'

The statement by Crow and Sarewitz (2001) is an example of some of the challenges borne out of high technology product R&D and commercialisation. More specifically, it suggests an intrinsic good 'story' with societal benefit, where all is clearly communicated. Unfortunately, there is a propensity of business discourse to be embedded within high-levels of positively based technical and functionality orientated language (Rogers, 2003). This can be problematic for the language constructed around sectors where nanotechnology is engaged with, and can create difficulties for different actors, including those within law to make sense and understand the product/technology (Beard and Easingwood, 1996). These aspects and others can create challenges and barriers to commercialisation of nanotechnology. With the majority of companies being engaged in nanotechnology R&D and commercialisation being within speciality chemicals, pharmaceuticals and semi-conductors, which all have their own stylised use of language, this problem has been further compounded (Lux Research Inc, 2004).

Nanotechnology and nanoparticle products are often poorly understood and as argued by Parent *et al* (1996), one of the greatest barriers to technology commercialisation is the lack of understanding of the technology itself, as well as respective uncertainties of risk and HSE considerations. Pecora *et al* (2003) found there was a gap between those with an in depth comprehension of the fundamental concepts of nanotechnology and those who believe they have an understanding. Castellini *et al* (2007: 183) demonstrated this point:

> '*It is often that people can actually comprehend that elements are the building blocks of all matter if they know basic facts about atoms. Additionally, it is assumed that people familiar with the metric system can truly conceptualise the minute size of the nanoscale regime. These erroneous assumptions lead to a disappointing lack of communication.*'

Although there can be challenges to understand technology products, there is often a high level of attraction, with both of these aspects being more thoroughly examined in the following section.

4.2.2. The Attraction and Challenges of Nanotechnology

Nanotechnology and nanoparticles have created much scientific and consequently regulatory interest. Scientific interest has predominantly focussed on technical aspects of nanotechnology and nanoparticles, particularly novel properties displayed at the nanoscale. As such these entities are becoming key components in a wide variety of disciplines including physics, biology, chemistry and engineering, for product areas including optical components, cosmetics, food technology, polymer science and medicine etc. (International Journal of Nanoparticles, 2014). Importantly, nanoparticles are one of the most widely used types of nanomaterial in nanotechnology, and can be used alone as a product or incorporated into other products to enhance functionality or pave the way to new IP. As mentioned previously, nanoparticles can be defined as '*ultrafine particle[s] with lengths in two or three dimensions [between] 1*

nanometre and 100 nanometres' (ASTM 2456-06). They can be composed of organics (carbon), inorganics (metal) or organometallics (a mixture of carbon and metals) giving great flexibility in product design. Nanoparticles are popular product choices for businesses due to the relative increase in surface area, as the materials are down sized to the nanoscale. This reduces the internal volume, which can be the non-profitable part of the product, but increases the surface area, which is more reactive and thus more profitable (Cientifica, 2003). The different sizes and shapes of nanoparticles and the ability to incorporate or bind them to other products have made them desirable commercial propositions.

The unique characteristics of materials at the nanoscale has allowed for a wide variety of commercial claims for numerous applications to be made. These claims routinely promise a range of health and environmental benefits, and construct nanotechnology as the next advancement of science, where great commercial benefits can be enjoyed by all (Gray, 2012). An example of this can be seen within therapeutics and medical diagnostics where nanotechnology has been discursively framed as *'the new industrial revolution'* (Bosso, 2012). Yet, the risks to human health and the environment have still not been fully assessed enough for a regulatory framework to be considered which would protect the ecosystem and humanity from unknown consequences (Wiesner and Bottero, 2007). Munshi *et al* (2007: 437) argue that:

> '*For many investors the promise of nanotechnology looks real enough to interest them, but what keeps them back is a coherent translation of the scientific jargon behind much of the research being carried out in laboratories.*'

It is not just a problem of language that is creating difficulties for nanotechnology but is also the uncertainty about the difference between nanoparticles and larger scale products. This is coupled with the unknown nature of nanoparticle products, particularly for toxicity, regulatory compliance, environmental impact, and how the longer-term commercial aspects of nanotechnology products (Oberdörster, Oberdörster and Oberdörster, 2005; Beer

et al, 2012). Aspects such as these can result in the rejection of emerging technologies if the perception of risk is too high (Sjoberg, 2000).

After considering some of the challenges and attractions of nanoparticles, the next section goes on to examine nanoparticle applications through a few examples.

4.3. Applications of Nanoparticles

Applications for nanoparticle-based products are of great interest to companies engaged in commercialisation. With increasing investment in this area (Lux Research, 2007; Gray, 2012), the question can be asked, what applications are nanoparticles used in? Looking back over the past decade, much discourse has focussed on the pervasive nature of nanoproducts targeting numerous sectors (Gray, 2012). The global market place for nanoparticle-based products has for some years been valued at tens of billions of dollars (USA) per annum (Woodrow Wilson, 2008). Suggestions from the Woodrow Wilson International Centre (2011) argued that 1,288 companies were producing 1,317 products in 30 countries. This is a potentially misleading figure as it failed to take into account that nanomaterials are commonly incorporated into other products, which potentially increases the number of nanoparticle products being sold (depending on how a nanoparticle or nanotechnology product is defined).

At present, it is difficult to find a sector in which nanotechnology, and nanoparticle products are not being sold into. This means that in practicality, there are a large variety of product functionalities, being used in a variety of product and sector based applications. Looking at nanoparticles, their greatest advantage for product use is the ability to increase product surface areas, while decreasing the cost-inefficient internal volume. Against limited attempts to regulate nanoparticle products based on their physicality as nanoparticles, it has made this collection of technologies an attractive commercial proposition for numerous companies. The pervasive use of nanoparticle products is shown in Figure 4.1.

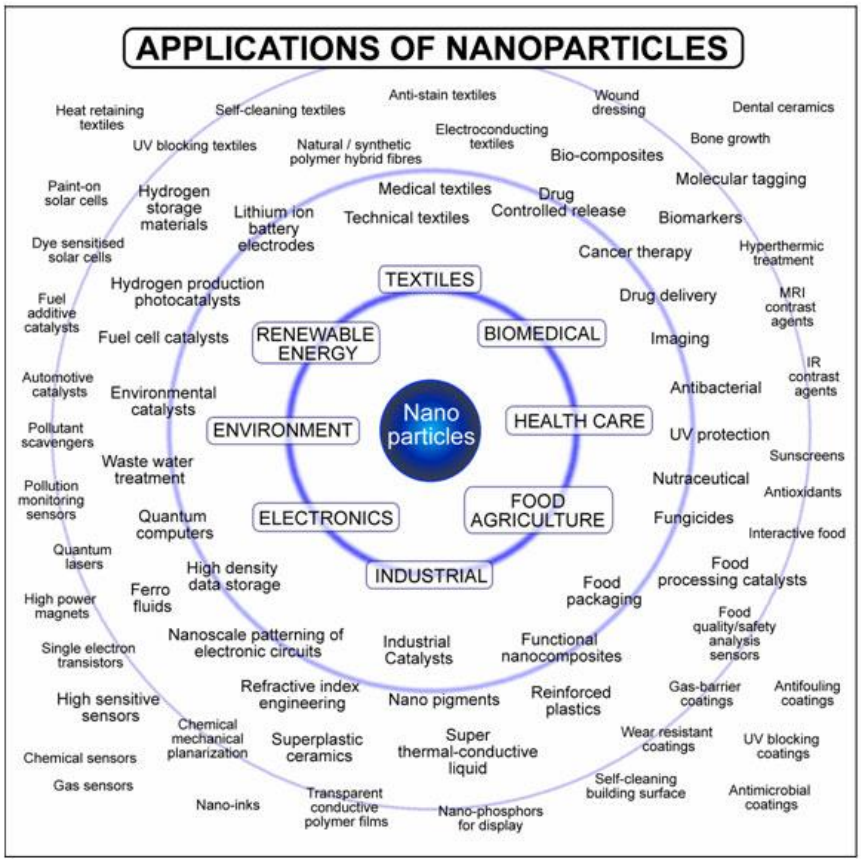

Figure 4.1. Commercial scale production of inorganic nanoparticles (IJNT, 2009)

Figure 4.1, shows a variety of nanoparticle applications within several main sectors where nanoparticles are currently being used, with further segmentations and product uses indicated throughout this diagram. As might be expected, based on the physicality of nanoparticles to bring 'benefit' to products, different sectors may well view nanoparticles differently, and potentially as a consequence of the regulatory landscape (albeit not nanoparticle specific), be willing to engage in R&D and commercialisation more or less than other sectors. Importantly though, the number of applications and products shown in Figure 4.1, which is not exhaustive demonstrates the pervasive nature of nanoparticles, and their wide usage across numerous sectors.

The following section draws on the application of nanoparticles and discusses some of the promises of nanotechnology demonstrating why the differences from the bulk make nanoparticles a preferential choice.

4.4. Applicative Differences from the Bulk

Fundamental to nanoparticle regulation, is the intended use of these products. As previously mentioned, there are a variety of applications that nanotechnology products are used in, with this number appearing to grow year-on-year. Drawing on numerous sectors and applications, this section pulls together some of the how and why of the differences between nanoscale products and their bulk larger scale counterparts. This is critical to understanding that nanoscale products are not simply a smaller version of large products, but are better viewed as highly nuanced, and often more complex counterparts, with many physical differences played out in their manufacture and life cycle.

The physical difference between nanoscale and bulk scale products is not always fully recognised in regulatory discourses, but importantly, authors such as Hansen *et al* (2003) argue that it is vital that regulations support this notion. This is not only a perceptive issue that supports the commercialisation of novel technologies, but one often grounded in physical studies. While smaller entities than their bulk counterparts, nanoparticles can create cosmetic benefits for their users, such as no white marks on the user (Nasir, 2011: WP), but can also create less well-known toxicological reactions, which must also be taken into account in their regulation. Nanotechnology is thus a physically distinct set of products and processes, and not simply a downsizing of previous products. On the one hand it can enhance old products, or create new products, all with potentially fundamental differences in physicality for the manufacturer and consumer.

Developing and using nanoparticle products has much potential for numerous sectors, often based on the smaller size of nanoparticles in comparison to larger products. The commercial interest in developing new tools, new products and commercially exploiting them can perhaps be best summed up by Josef Kokoni, the director of the Center for Advanced Food Technology at Rutgers University (nanowerk, 2012) who commented that *'every major food corporation has a program in nanotechnology or is looking to develop one*.' From this statement it is clear that nanotechnology is no new trend, but a new series of industries and products opening up, often through radically different technologies. Looking

further at food to demonstrate this point, the question can be asked what is nano food? The multifaceted nature of market penetration from a diverse range of research and commercialisation activities suggests that there are numerous aspects to be considered, including nanotechnology being a new way of making food, incorporating things into already existing food, packaging food, and labelling food. The perception of nanotechnology food has been cited as pivotal for commercial success (Hansen *et al*, 2003), and as such it is vital that regulations support this notion. Like many other nanoparticle applications, there are many commercial drivers that have facilitated a growing interest in food nanotechnology, which in part can be linked to the potential size of the global market, large potential market shares for new market entrants, IP protection and perceived profitability etc. (Helmut Kaiser Consultancy, 2005).

The creation and commercial exploitation of nano-food is receiving much governmental and regulatory interest, particularly in the commercial sale of such products. According to the National Science Foundation, nanoparticles are being used for a wide variety of purposes, and for instance, to increase the absorption of nutrients contained in food and beverages such as fruit juice, tea and wine (Joseph and Morrison, 2006). Technological innovation has resulted in research into 'on demand' foods that will lay dormant in the body delivering nutrients to cells as and when needed. This is a paradigm shift from current nutrient delivery, which is by the controlled uptake of an individual, predominantly ingesting nutrients. These on demand nutrients have been designed for use in nanoscale capsules that will be incorporated into food with the addition of nanoparticles to better enable absorption (Joseph and Morrison, 2006).

For high technology and in particular nanotechnology regulation, there is always the potential that what appears as science fiction today may very well become science fact tomorrow, with regulation having to potentially address these changes. Since the publication of Drexler's (1986) book '*Engines of Creation*', much of the focus of nanotechnology has been geared towards healing humans, but has at times been framed in science fiction terms rather than science fact (Davies, 2011). Health related nanotechnology exists within this paradigm, which can create opacity and challenges for non-technical specialists to engage

meaningfully with nanotechnology and the rapidity of change. Nanotechnology related to health creates even greater confusion due to a prerequisite for legal actors to not only engage with nanotechnology but with the complex areas of medicine and health, which also have their own specific discourses, meanings and regulation.

With many socio-economic drivers for reducing disease and increasing public health, many countries are turning to the potential of nanoparticles and in a wider sense nanotechnology to reduce infections and to heal disease states, particularly in humans (Nanomedicine, 2012). Within the push for eradicating and limiting disease is the internal pressure within manufacturing companies for novel products to be commercialised that produce a high return-on-investment for the developing company (Nanomedicine, 2012).

One of the many beneficial ways that nanoparticles are being applied is in the medical field, leading to novel means of imaging living systems and of delivering therapy (Provenzale and Silva, 2009). Much of this research is focused on methods for imaging central nervous system functions and disease states. In addition to innovative forms of imaging, other therapeutic uses of nanoparticles include, drug delivery systems, neuroprotection devices, and methods for tissue regeneration. Research teams around the world are developing nanoparticles, which can be used in many ways to detect and treat different forms of cancer (Provenzale and Silva, 2009). An example of this is gold nanoparticles being used to target brain tumours with the advantage of being able to cross the blood brain barrier and be target specific (Jain *et al*, 2012).

At present there are numerous health related and skin protecting agents, which utilise nanoparticles. Most simply they are a relatively inexpensive and simple way to 'pack' the product with more 'active' ingredient (Dana, 2012). Demonstrative of this point, the use of nanoparticles in suntan creams can be considered (Nasir, 2011: WP):

> '*While widespread use of this technology is currently under evaluation, I think one of the main benefits of nanoparticles used in*

sunscreens will be that the particles can fit into all the nooks and crannies of the skin, packing more protection and more even coverage on the skin's surface than microsized particles…..Since sunscreen formulations using nanoparticles may be more cosmetically appealing and seem to vanish when applied, consumers may be more inclined to use them on a regular basis.'

In the arena of cosmetics, and in particular for numerous pharmaceutical and anti-aging products, nanoparticles have been seen to play an important role by delivering active ingredients to the skin by using time release application and patch delivery systems using nanospheres and nanoparticles. Thus, there is a cross over from drug delivery systems based on nanoparticles and cosmetics, which enables large companies to leverage their expertise in other areas and increase their exploitation of knowledge across products.

According to Kaur and Agrawal, (2012) nanoparticles have triggered a 'revolution' so that *'cosmetics are no longer visualized as products that cover up or camouflage imperfections in personal appearance.'* By combining patented delivery systems together with clinically 'proven' ingredients and the aesthetics of fine cosmetics, a new type of product *'cosmeceuticals'* is set to bridge the gap in the market between cosmetics that *'cleanse and beautify'* and pharmaceuticals that *'cure and heal.'* The Freedonia Group Inc. Cleveland Ohio claim that there is such a great demand for these 'cosmeceuticals' to enhance personal appearance, that these products are projected to increase by approximately 12 percent per year. This would make cosmeceuticals a dynamic sector in the personal care and cosmetic industry (Kaur and Agrawal, 2012).

Finally, after the examination of different aspects and areas within this section, the next section, the summary draws this chapter together.

4.5. Summary

This chapter has examined the use of nanoparticles in the commercial world of nanotechnology. Drawing on a collection of perceived benefits and challenges to companies in this area, a spectrum covering the drivers and difficulties for commercial activities have been explicated. This has been alongside an exploration of the applications and the commercial value of nanoparticles, as well as highlighting specific risks that will need to be addressed through regulation. Importantly, while the benefits and risks can at times be clear, yet again, the framing of nanoparticles as an inherently 'beneficial' or 'dangerous' collection of products is argued against as unhelpful.

As argued in this chapter, there are clear commercial and social benefits for product commercialisation utilising nanoparticle-based technologies. While these benefits can routinely be drawn on to argue for a regulatory status quo to be maintained, this misses out much of the risk, and potential need to insure these products. Against a backdrop of uncertainty and what is frequently a low-level of knowledge about how nanoparticle products will act in the short, medium and long-term, the following chapter goes on to look at nanoparticle risk and insurance, which is a critical and inherently important aspect of nanoparticle commercialisation, and potentially regulation.

Chapter 5. Nanoparticle Risk and Insurance

5.1. Introduction.

This chapter is broadly driven by the research question 'How are nanoparticle products perceived from a risk perspective, and how does this influence their insurance?' The aim of this chapter is to examine risk and insurance for nanoparticles and in a wider context nanotechnology. These aspects are considered against a backdrop of the complexities of high technology products including the opaque arena of nanoparticles, where there is often much uncertainty and confusion over product physicality, in turn impeding decision-making. Within this area, there is much debate regarding nanoparticle risk and insurance, particularly linked to inherent product uncertainties. While it is accepted that unknown and unregulated risk may influence and impact on the risk assessment and insurance of all high technology products, this chapter highlights why this is even more problematic for nanoparticles examining perceived pertinent risk management strategies as well as the precautionary principle, to assess their perceived effectiveness for nanoparticles as a collection of products, as opposed to being a single-entity. The future of these technologies as ever changing products is considered for risk and insurance. Section 5.3 specifically addresses four regulatory issues raised from insuring products containing nanoparticles. The first issue to be considered will be the uncertainty of whether typical insurance policies currently do cover the risks from nanoparticles. The second issue is the risk that insurers might begin to withdraw cover from activities such as manufacturing or selling products that incorporate or are based on nanoparticles, and thus if the availability of insurance becomes a problem, how this might be addressed. The third issue is whether manufacturers are choosing to acquire sufficient insurance cover, assuming it is available, and if not, whether we should regulate for manufacturers to do so and the fourth issue is the challenge of insuring nanoparticle products.

As a starting point to this chapter, the following section examines risk.

5.2. Risk

To set up the consideration of nanoparticle and nanotechnology risk, this section sets out to briefly overview risk as a perceptual lens and practice. The term risk is commonly used in many disciplines, and in particular law and business to construct and describe realities that have known/unknown and expected/unexpected outcomes, with this aspect being engaged with more in Section 2.2.2. A predominantly negative lens is often used to categorise risk as being undesirable, which has led to numerous driving factors to understand and minimise risk. As an example of risk as a negative, Ball (2003) defined risk as being, '*a situation involving exposure to danger*'. Critically, while the predominant view of risk is negative, risk can also provide beneficial but potentially unexpected results i.e. serendipitous business outcomes. It is however the negative aspects of risk that is pertinent to this study, as this is predominantly the lens used for legally examining risk, to mitigate this aspect (Marchant *et al*, 2008).

Risk management has received great interest from multiple disciplines including law, with numerous approaches being taken to examine, understand and mitigate risk. While various approaches to risk have been taken in different academic disciplines, law has been particularly active with regard to high technology products. Throughout this section, concepts within traditional risk management are considered, alongside whether they can be considered fit-for-purpose for complex and opaque high technology products. The traditional model of risk is predominantly based within a framework of cost-benefit analysis, where the risks of a product are weighed up against the precautionary principle. Simply, costs and benefits are considered against each other and within the shade of the precautionary principle, which promotes the view of being *'better safe than sorry.'* Models such as the cost-benefit model (neweconomy, 2015), have the advantage of potentially being relatively simple to facilitate decision-making, but can be at the expense of getting to grips with the '*nuts and bolts*' of a product.

High technology products are arguably more difficult for risk management, which must be negotiated by all parties engaged with these products. This is

based upon different stakeholders and for instance, R&D companies, sales companies, buying companies, legal actors and insurers etc. having different levels of knowledge, using different styles of discourse and language to engage with products not easily understood. All of the decision-making processes required for risk management are against a backdrop of wider perceptions of high technology product risks, such as nanotechnology being constructed as a general panacea (Papazoglov and Parthasarathy, 2007) and at the same time being the greatest risk the world has ever faced (Lloyd's, 2007). Of pivotal importance to the ability to manage risk is the ability to understand what nanoparticles are as a product class, how they work, and how they are the same/different to other products, which have already undergone risk management. These aspects all feed into the ability for companies to make marketing claims about products, minimise their liability and communicate to the market and various stakeholders about products directly and through labelling. While all of these factors are important, it is how law views them that is of interest to this study.

As a backdrop to risk, and in particular high technology products, the nature of commercialisation has risk weaved throughout it (2020 Science, 2012). Hodge *et al* (2010) has argued that risk is inherent throughout business practice, particularly product development and commercialisation, which thus necessitates involvement from law. Areas that law may engage with are shown in Table 5.1.

Business Activity	Description
Breaching internal self-regulation	Carrying out activities that breach internal guidelines and exposing the company to risk.
Breaching network-regulation	Carrying out activities that breach network guidelines and exposing the 'offending' company to action from the network.
Breaching governmental regulation	Carrying out activities that breach governmental regulation, such as failing to disclose product toxicity, and exposing the 'offending' company to action from a government or regulatory bodies.
Competitor action	Action from competitor companies or networks that result in known or unknown risks to a company.

Table 5.1. Business practice, law and risk.

Although demonstrative of the areas that law may engage with, Table 5.1. has not produced a totality of legal risk but more highlighted key macro areas. Within these or other macro areas, is the need for law to dig deeper into the minutiae of business practice, particularly for high technology. Importantly, there is not necessarily a 'right' answer for the engagement of law with high technology product risk, as the notion of risk often changes. Drawing on the thoughts of Slovic (2011: WP), '*man learns by trial, error and subsequent corrective actions to arrive at a reasonably optimal balance between the benefit from an activity and its risk*'. While this might be considered a luxury, as disasters such as Thalidomide are to be avoided, in practicality, no matter what the system used, the practicality of risk regulation is that it is an adaptive and evolving process.

Within any strategy that may result in 'action' in the physical world, there is a balancing act that must take place between perceived risk and benefit, which must be negotiated. This may flow into what factors need to be mitigated as well as what is acceptable from many different perspectives by the introduction of new policies to mitigate the risk and advance the commercialisation of perceived beneficial technologies (Starr, 1972). Looking at this further, Starr (1972) claimed that, (1) the public seems willing to accept voluntary risks roughly 1,000 times greater than involuntary risks at a given level of benefit, (2) the acceptability of a risk is roughly proportional to the real and perceived benefits, and (3) the acceptable level of risk is inversely related to the number of persons participating in an activity. This is potentially a complex mixture of factors, but does suggest that knowing the acceptable risk level for each activity is paramount, as is the perceived risk. Eliminating uncertainty may also mean eliminating the technology and losing the benefits or by trying to eliminate the uncertainty, the technology could be altered. Thus some risk may at the same time be inevitable and also desirable (Slovic, 2011) as a consequence of commercialisation. These may be important considerations for nanotechnology products, particularly in light of the confusion and uncertainty currently surrounding them.

Cost has been linked to high technology product decision-making when making risk assessments (HSE, 2001). Slovic (2011) has claimed that there are four main areas when carrying out risk analysis on a new technology, which include, if; (1) the benefits outweigh the cost; (2) the risks are no greater than those of currently tolerated technologies with equivalent benefit; (3) the public accept the risks; and (4) the risks are no greater than those accompanying the development of the human species. Within this range of requirements is the backdrop of public perceptions that are constructed for new products, often based within the shadow of prior and potentially unrelated products, which can either facilitate the sale and adoption of new products, or negatively stigmatise them. Regulators are often keen to keep abreast of public perceptions for risk with claims being made that at worst regulators engage in 'knee-jerk' reactions to publically perceived risks (Abraham and Lewis, 1999). While this is perhaps an over-statement, there is a need for regulators to be perceived as being attentive to current social perceptions of products.

Importantly, the actual risk can be very different from the perceived risk, and an example of this is bovine milk containing bovine growth hormone (BGH), which was rejected due to negative public perception of the product. This led to numerous supermarket chains refusing to buy or sell any milk products from cows treated with BGH (Elmer-Dewitt, 1994). Importantly, even though WHO (1999), FDA (1999), and NIH (1990), all stated that meat and milk from BGH cows were safe, issues were still raised about the dangers of BGH, including to animal welfare (Doohoo, 2003) and human health (Collier and Bauman, 2014). This makes risk management particularly problematic, when there are competing narratives about the risk of products, which is arguably compounded by the challenges of understanding high technology and the language used. Speculatively, it is worth considering that as the technology becomes more opaque and complex as in the case of nanotechnology, the more difficulty there is in predicting the risks. Nanoparticles are well known for being ambiguous and poorly understood technologies, and the next section explores nanotechnology risk to explicitly consider perceived and physical risks from nanoparticles.

5.2.1. Nanotechnology Risk

Nanotechnology is a highly pervasive collection of technologies, with it having been speculated that there are over 116,000 products within the global marketplace (CPI, 2014). With this number being expected to increase there is a clear driver to more deeply understand nanotechnology and nanoparticle risk, as well as how to manage and regulate this risk. According to Marchant *et al*, (2008: 3) *'Nanotechnology presents both an unprecedented challenge and an unparalleled opportunity for risk management'*. Perhaps most problematically is the notion that 'we don't know what we don't know' about nanoparticle products and nanotechnology. While speculative offerings can be produced, little information is grounded within scientific testing, hindering test-driven knowledge. Even though there are multiple shortcomings, Table 5.2 details some of the key perceived nanoparticle risks.

Nanoparticle Risk	Examination
Size.	Arguably the perceptive lens of risk changed with nano, and raised small size as risk-laden. Prior technologies such as asbestos as 'small' and 'toxic' may have fed into this narrative.
Distribution of nanoscale phenomena.	There is a 'current' perception that nanoparticles are all the same size and shape etc. This is not the case, and it is possible that a variety of sizes and shapes of nanoparticle products may have their own toxicities. Little is being done to address this issue.
Socio-cultural discourse.	Varying discursive framing is creating 'good' and 'bad' stories about nanoparticles. Similar technologies, such as GMO have faced the same challenge. This issue sits in and outside of law and is arguably the most challenging aspect.
Definition.	Nanotechnology suffers from a lack of legal definition, particularly for whether it is an incorporated material into a larger product, it is a nano-entity on a larger product etc.

Table 5.2. Nanoparticle risk (Marchant et al, 2008: 3)

Within the multitude of Risk management strategies are traditional risk management principles, which include acceptable risk, risk analyses, and a feasibility aspect often known as best available technology, which includes the precautionary principle (Grunwald, 2008). An argument has been made that these strategies are potentially inadequate for high technology products (Phoenix and Treder, 2003), with suggestions that new strategies are needed.

The perception of nanotechnology is an important issue particularly when assessing risk. Satterfield *et al* (2009: 752-758) stated that it is essential that *'emerging trends in public perceptions of nanomaterials be critically examined for those who regulate risks'*. Public perception may jeopardise the development of nanotechnology as demonstrated with GMO, recombinant DNA technology and nuclear power. Sheetz *et al,* (2005: 335) states *'[o]ne of the greatest challenges facing nanotechnology is avoiding a backlash from the public that slows or even halts the progress of research and development*'. The ways that individuals engage with risk is however complex and is shown in Table 5.3.

Vehicle	What it is and how it works
Heuristics	A mental problem solving technique. '*Heuristics serve people well in many circumstances, but they also create vulnerabilities to the predations of advertisers, political spin doctors, trial attorneys and ordinary con artists*' (Rachlinski, 2003: 1165).
Heuristics (Affect)	The *'affect'* heuristic is most applicable for nanotechnology and *'refers to people's tendency to rapidly and automatically have positive or negative feelings when confronted with a certain word, concept or other stimulus'* (Mandel, 2005: 161). If an individual perceives benefits to a technology, the risks of that technology are believed to be low, which is conversely true for high-risk technology (Slovic, 2000).
Heuristics (Availability)	*'The availability heuristic captures the mental process by which people assume that events more easily recalled are more likely to recur*' (Sylvester and Lohr, 2005; in Marchant *et al*, 2008: 18). If an individual recalls a memory linked to harm, they will be predisposed towards the over estimation of the probability that it will recur.
Temporality	The risk of an event is coloured by when it occurred. Something fresh in the mind can colour an individual's judgement.
Stigmatisation	Media coverage and discourse as well as stakeholder communication can create an imbalance of information *i.e.* 'stigmatisation'. It has a far-reaching effect beyond perception of risk attached to a technology (Slovic, 2000). As Sunstein (2003b: 759) stated: '*representative anecdotes and gripping examples can move rapidly from one person to another. Once several people start to take an example as probative, many people may come to be influenced by their opinion, giving rise to cascade effects…[a] problem [that] might well be aggravated by certain media and new technologies*'.

Table 5.3. Ways We Engage with Risk.

While this study is embedded within a legal paradigm, it is important to engage with the driving social forces for the way that nanotechnology risks are perceived as shown in Table 5.3. This may be critical for nanotechnology, as it has become susceptible to cascade effects from these social aspects, which negatively impacted prior technologies such as GMOs. Against a backdrop where some believe that *'functional discourse… is largely absent from technology debates,*

and the climate necessary for productive discourse is poisoned' (Mandel, 2005: 117), is a requirement for risk management to deal with this aspect. Without critical engagement with this area, the negative publicity surrounding nanotechnology, may well create a bleak outlook due to the over estimated probability of risk. Yet this bleak picture is not the only way forward for nanotechnology. The heuristic processes have the potential to over estimate the risks but it is possible that the benefits are seen to outweigh any risk. This is because *'affective'* attitudes could also create perceptions of desirable benefits produced by *'availability'* cascades. This reasoning could offset any reasoning that is risk based. It is not known at this stage whether the risks of nanotechnology outweigh the benefits (Sheetz *et al,* 2006). It is necessary therefore for action to be taken to reassure the stakeholders, individuals and organisations in some form. This can be challenging though when the wider aspects of prior high technology commercialisation is considered, particularly the more problematic technologies. Thus, the following section considers prior technologies and nanotechnology risks to explore this aspect further.

5.2.2. Prior Technologies and Nanotechnology Risks - Asbestos

The commercialisation of prior high technology products has resulted in multiple narratives being produced ranging from 'good' to 'bad', and have at times echoed into the launch of new technology products. Thus nanotechnology and nanoparticle products exist in a sea of discourse, where reasons for framing a product as safe or risk-laden are to varying degrees rational. In this section, asbestos is considered as an exemplar of a material class widely used in many technologies that led to 'eventual' perceived risks as well as more understood physical risks.

Asbestos is a naturally occurring crystalline fibrous silicate material, mainly used in heat insulation among other areas, which is frequently highlighted as 'what might go wrong with nanotechnology' (Poland *et al*, 2008). At present asbestos is known to cause disease states (asbestosis) and is the main cause of malignant mesothelioma cancer in humans (asbestosvictimadvice, 2013). Problematically

for determining adverse effects, it has a long latency period but once manifested death can often occur within a year (UNESCO, 2006). Health experts from the EU predict that deaths from mesothelioma, lung cancer and asbestos could reach between 250,000 – 4000,000 over the next 35 years due to exposure from asbestos.

Importantly, asbestos has been used for over two thousand years, where there have been over 3,000 commercial products containing asbestos including, clothing, floor tiles, textiles, roofing and cement piping (Manning, Vallyathan and Mossman, 2002). Arguments have been made for hundreds of years about the potential risks from asbestos that might necessitate regulation (similarly to the use of certain non-asbestos nanotechnology products today). It has been stated that in 1879 when industrial scale mining of asbestos was started, the dangers from asbestos were relatively unknown. Using hindsight, it could be argued that it is possible to claim almost any product 'disaster' as foreseeable, with a need for such claims to undergo some level of validation. Clearly, with any product health related failure, the notion exists that there 'must have been signs'. While this is at some level true, without an adequate reporting system, signs, as in the case of asbestos can and were missed. This is not to say that concerns were not raised, as examining Table 5.4, a detailed timeline of asbestos related health issues, has been put together potentially acting to show adverse effects from this material used in many products (UNESCO, 2006: 10).

Year	Health 'Evidence'
1898	Lucy Deane, a factory inspector, first warns that asbestos dust has a potential to cause harm to workers and those exposed to it.
1906	50 deaths amongst female asbestos textile workers were reported by a French factory. A recommendation for controls was made.
1911	Experiments on rats demonstrate *'reasonable grounds'* to believe that asbestos dust is harmful.
1911 and 1917	The UK Factory Dept. decides that there is insufficient evidence to validate any action to be taken.
1930	'The Merewether Report' (UK) reports that 66 percent of workers in Rochdale show signs of asbestosis.
1931	Asbestos Regulations (UK) stipulated asbestos dust control but only in the manufacturing process. Compensation to be awarded for asbestosis but this is poorly implemented.
1935-1949	Asbestos manufacturing workers report high incidences of lung cancer.
1955	Research carried out by Richard Doll (UK) found a high risk of lung cancer in Rochdale asbestos workers.
1959-1964	Mesothelioma cancer was identified in asbestos workers' neighbourhood in South Africa, USA and the UK.
1998-1999	The EU and France ban asbestos in all forms.
2000-2001	Canada appeals the EU and French ban but the WTO upholds it.

Table 5.4. A timeline of asbestos 'evidence'.

It is potentially easy to look at Table 5.4 and inquire why more was not done to limit the impact of asbestos on human health. The 'evidence' of adverse effects might appear to have indicated there was a problem decades before anything was carried out to limit the negative impact of this material. While it can be argued that not enough was known, the backdrop of positive promotional narratives from vested commercial parties cannot be ignored. Examples of quotes, taken from the Chillicothe Constitution Tribune (1936: 9) highlight this with the advert: '*[p]ink asbestos aprons for careless ladies who lean on stoves sizzled into the International Fashion Market today from Great Britain*'. Asbestos was also advertised as a material to be worn by young children.

'*For little girls anything is good that even has a suggestion of the Shirley Temple styles. Fine broad – cloths and silk prints are the most popular materials. For little boys there are [two] – piece knits and for boys just a little older there are worsteds in a tailored coat and short trousers.*'

Beyond positive commercial narratives, the main reason for delay in action against risk associated with asbestos was due to the length of time between exposure and symptoms being displayed, and a lack of a reporting system legally mandated that would pick up on adverse effects. With no reporting system, the burden of demonstrating scientific proof that asbestos has adverse effects significantly delayed any risk reduction regulation being put in place. All of the early warnings from 1898 – 1906 were 'ignored' and little precautionary action undertaken. Further to this, no surveys were carried out to monitor long-term dust exposure (EEA, 2001). Highlighting the problems that may ensue from asbestos exposure and adverse effects, the following has been argued (Canadian asbestos: a Global Concern, 2003: WP):

'*The asbestos cancer epidemic may take as many as 10 million lives before asbestos is banned worldwide and exposure is brought to an end. The battle against asbestos is in danger of being lost where the human cost may be the greatest in developing countries desperate for industry.*'

In 1979, a potential scapegoat for asbestos was provided by Sells (1994) claiming that asbestos workers who smoked were fifty times more likely to contract lung cancer from tobacco than from asbestos. This prompted the tobacco industry to take refuge in government mandated warnings that served them as a defence against product liability claims. This highlights a very difficult issue with unpicking adverse effects, in that even within statistically large populations, lifestyle choices can make it challenging to understand what is causing the adverse effect. This is shown in the pharmaceutical sector, where a pharmacovigilance 'yellow card' reporting system to warn manufacturers and health agencies of drugs with adverse effects is useful but difficult to 'get right'

(Amery, 1999). In the pharmaceutical sector, the reporting system has been underused with little incentives for stakeholders to provide data that there is a problem, which may also be the case with areas like asbestos, and maybe even nanotechnology.

Looking at asbestos, it appears that there was a culture of denial with the companies involved (Sells, 1994). Lessons should be learned from the 'poor' regulation of asbestos and the denial by both governments and companies of the dangers associated with asbestos products, when dealing with nanotechnology products until they have been proven to be safe. The misuse of asbestos has caused thousands of deaths, destroyed an industry as well as wiping out a huge percentage of stockholder equity (Sells, 1994). The severity of asbestos and the damage it did should not be underestimated, particularly for harm to humans, but also for casting a shadow over future technologies, where risks might be weighed against asbestos.

Within the UK, it took until 1985 for asbestos materials (blue and brown) to be banned, and until 1999 for the import, sale and second hand reuse to be prohibited, arguably meaning there was a fourteen year period with a potential for adverse effects from asbestos sale and use. Finally, the 2012 Control of Asbestos Regulations was enacted to stipulate the management of asbestos currently in buildings, with a requirement for employee training in specific handling of this material. More than this though, control limits for asbestos in working environments were set out alongside particle sizes, that are not themselves 'safe' but should raise serious concern in operating environments. Importantly, and with a 'long history' this shows that even in an industrialised country such as the UK, and 'known' health risks, it took many years for the material to be banned, and more 'adequately' regulated in the environment.

Asbestos is not just an abstract prior technology unrelated to nanotechnology products other than through a vague concept, as carbon nanotubes (CNTs) are currently being argued as physically similar in nature to asbestos (RSC, 2008). CNTs are cylindrical carbon based tubes, that are long, thin, and approximately 1 - 3 nms in diameter by 100s – 1,000s of nms long (azonano, 2014). Applications

include fuel, solar cells, electronic and optical devices, and batteries, amongst others (azonano, 2014). According to the Royal Society of Chemistry (2008), carbon nanotubes have similar qualities to asbestos fibres in that they are long and straight and of a comparable size and have been shown to cause cancer in lung cells in mice (Poland *et al*, 2008). For this reason toxicologists have indicated that those working in the production and disposal of CNTs are at risk of asbestos like illnesses particularly if exposure is from inhalation (Greenemeier, 2008). Donaldson from the University of Edinburgh (2008: WP) stated:

> '*We need more research on the toxicology of these materials, and the exposure to them in workplaces. Anything that's thin, long and doesn't dissolve in body fluids has got to come under suspicion as behaving like asbestos*'.

Caution when working with CNTs first gained prominence in 2006 (Van Noorden, 2008: WP) when it was stated:

> '*tubes that resemble asbestos should be treated as though they were asbestos and regulated accordingly. In this way, workers involved in their manufacture, use and ultimate disposal will be protected*'.

The chief science advisor with the US based project on Emerging Technologies, Andrew Maynard claimed: *'There are voluntary agreements for reporting in the UK and the US that not too many companies have signed up to*' (Van Noorden, 2008: WP). Thus there is the potential for monitoring, even if it is limited in practicality. It is expected that nanotechnology will suffer if the public as well as stakeholders lose faith through linking CNTs and asbestos, with the argument that '*It is up to governments to give industry as much guidance as possible*' (Van Noorden, 2008: WP). The next section moves on to consider existing risk management principles that can potentially be used for such materials.

5.2.3. Existing Risk Management Principles – Acceptable Risk

Arguably, risk is inherent with all social and physical activities, with there being a notion of acceptable risk, which can vary for what is acceptable. While it is not possible in this study, or desirable to go through numerous accounts of acceptability within existing risk management strategies, a broader approach of examining the macro concepts of these aspects is considered in this section.

Determining risk can be argued as a mix of subjective and objective elements, depending on how it is carried out, where acceptability is often determined through cultural notions at any point in time. Thus what is acceptable today might not have been yesterday, and may not be tomorrow. Practically, and pragmatically, risk assessments are utilised to 'determine' and set an acceptable level of product or technology risk at a certain time point. The nature of the qualitative and quantitative aspects of risk assessments is beyond the remit of this study, where it is important to understand that many approaches to determining risk and acceptability can be used, but the minutiae of how they work is beyond this study.

Current discourses regarding the understanding of nanotechnology places risk as being too uncertain to permit meaningful risk assessments, which are hindering meaningful methods to address this area, and thus reduce risk, or even determine what is an acceptable risk. This situation is likely to remain relatively static for some time, until there are sufficient, social, business, scientific and legal drivers to more adequately tackle this area and a more strategic examination of supporting knowledge of the physicality of nanotechnology and risk (Oberdörster *et al*, 2005; Lin, 2007). An example of the lack of knowledge and testing regimes to understand nanotechnology-based products is shown from the lack of acceptable test methods and validated data available to allow credible quantitative and fit-for-purpose estimates of the potential risks that are specific to nanotechnology (Sweet and Strohm, 2006; SCENIHR, 2007). This is further demonstrated from studies that have been carried out but have been at best preliminary and exploratory, but unfortunately framed as being confirmatory and fit-for-purpose (Sweet and Strohm, 2006; Nel *et al*, 2006). Such studies highlight

the complexity of nanotechnology risk assessments, but also the often unsupportable claims made from reports, which leads to further opacity in communicating, creating and facilitating the toxicological risks of nanotechnology products to better regulate these areas. Of pivotal importance from these studies, is the repeatedly echoing discourse that it is at the moment not possible to provide over-arching themes for product safety, and that a case-by-case basis for product safety testing must be carried out instead, which is no small task (Florini *et al,* 2006; SCENIHR, 2007; Greenwood, 2007). This is a daunting prospect for companies engaged in R&D, sales, marketing, risk management and regulation.

Current testing proposals by Florini *et al* (2006) to create a platform for risk management have been criticised as being unlikely to be carried out by scientists due to the cost and time associated with these activities. Marchant *et al* (2008) have stated that this issue is crucial to risk management due to the high number of products that contain nanomaterials already in the market, and where there is an indication that a high number of workers and consumers, have already been exposed to nanoparticles and are still being exposed. Thus, regulators are perceived as operating with a lack of sufficient information to make decisions that would facilitate regulation (Florini *et al*, 2006). In 2007, the EPA issued a white paper providing a time line for oversight stating that it would take approximately four to five years for the agency to have sufficient risk knowledge to develop a risk strategy to develop for managing nanotechnology risks (U.S. EPA, 2007: 112). By this time the majority of all citizens globally will have been exposed to nanomaterials in some form or another. New generations of products will be entering the market with their new risks and uncertainties, and with seemingly little to stop or regulate this aspect. As stated by David Rajeski of the Woodrow Wilson Centre (2004: 45), *'[i]f you think that any existing regulatory framework can keep pace with this rate of change, think again'*. Discourse regarding nanotechnology risk assessments has been predominantly negative towards risk management and as argued by Morrisey (2007 In: Marchant *et al*, 2008: WP). '*We are in this awkward middle territory where we have just enough information to think that there is an issue, but not enough information to really inform policy makers about what to do about it*'. More than this though is the

rapid pace that nanotechnology is being developed, as it is 'outpacing' any risk assessment development (Renn and Roco, 2006).

Finally, the development of risk assessments for nanotechnology is arguably needed, current risk based approaches are only providing a primary risk management solution for the short term due to the rapidity of technological innovation. Acceptable risk strategies suffer from certain structural disadvantages. For example, if only the acceptability of risk is considered, then other factors such as the importance of nanotechnology is disregarded. These factors include the cost of reducing any risk as well as any benefits and are important for when making any decision about nanotechnology.

Following on from the aspects discussed in this section, is the examination in the next section of risk analyses, which considers the vehicles, used to analyse nanoparticle risk.

5.2.4. Risk Analyses

Within risk management studies for high technology products is the ability to use several types of analyses, to determine risk, which can be compared against potential benefits. These analyses include cost-effectiveness analyses (Bleichrodt and Quiggin, 1999), cost-utility analyses (Black, 2002), risk-benefit analyses and cost-benefit analyses (Boardman, 2006) amongst others. Arguably the most popular choice for carrying this out is cost-benefit analyses, which is a collection of processes and models used to (1) determine if there is justification i.e. a sound basis for carrying out an activity/endeavour, and (2) to provide a basis for comparing outputs and projects (Boardman, 2006). The second model of particular importance is that of risk-benefit analyses, which seeks to quantify risk against benefits to facilitate decision-making. For businesses, both of these models are important to understand the relationship of cost and risk to benefits.

Models have a lot to offer regulation, to better determine how nanotechnology should be regulated and as a way of 'calculating' the cost/benefit for example.

As Gwinn and Vallyathan (2006: WP) highlighted for instance, current potential models are: '*ill – equipped for managing nanotechnology at this time, given the immense uncertainties about its risks and benefits'*. Looking beyond this statement, Marchant *et al* (2008: WP) claim that prior models are *'unfeasible'* due to the *'global cost – benefit balancing for nanotechnology as a whole would mask the significant cost – benefit variance that likely exists between different applications'*. The narrative constructed by such academics suggests that when looking at the total number of potential applications of nanotechnology and specifically products, the notion of performing a specific cost-benefit or risk-benefit analysis for each product could overwhelm any available resource given over to risk management. The suggestion appears to imply that while a useful 'paper exercise', in practicality the resource and cost to do so would be prohibitive. Such tools may therefore inform decision-making and produce a more in-depth understanding of products, but may also be limited in scope and capability.

The traditional risk management approach incorporates the 'feasibility' or 'best available technology' model. Here the risk is reduced to the lowest possible level that is economically or technologically feasible. This approach is very popular amongst policy makers as it potentially allows any controversies arising from risk analysis to be circumvented, thus allowing potential risks to be reduced (Shapiro and McGarity, 1991; Wagner, 2000; Babich, 2003; Drieson, 2005). This can be appealing for technologies such as nanoparticles, however it is not without weakness as it often ignores risk information. Utilising this approach can result in an either an under or over regulation, and raises the question of how it can be used for complex products as found within nanotechnology and nanoparticles? Arguably none of the traditional risk management models and analyses has the capacity to manage risks from nanotechnology effectively due to the amount of existing uncertainties surrounding this varied collection of technologies. This has precipitated an application of the precautionary principle to nanotechnology, which leads to the next section, which considers risk and the precautionary principle.

5.2.5. Risk and The Precautionary Principle

In recent years the precautionary principle has emerged as an alternative approach to risk management and can be summarised as 'better safe than sorry'. The precautionary principle is based on a recognition that decision-making often occurs in situations of uncertainty, where decision-makers can be required to err on the side of caution. This often means that new technologies are delayed until their safety can be 'proven' or 'ensured', and can require a demonstration of product safety, which is a well-debated concept in other high technology areas of medical devices and pharmaceuticals etc. (Mann and Andrews, 2014). As there are arguably many unknown risks and uncertainties surrounding nanotechnology, there is often an assumption that the precautionary principle is an ideal solution to aid decision-making. Yet there are limitations, which are detailed in Table 5.5.

Limitation	Description
Poor definition	The precautionary principle is too poorly defined to be used as a decision-making vehicle, which can be particularly problematic where there is also a lack of understanding about the product it is being applied to (Sandin, 1999).
Lack of text	There is no standard text available for the rule, and conflicting text about nanotechnology and nanoparticles (Sandin, 1999).
Unable to answer questions	The precautionary principle is unable to answer questions that are imperative for regulatory decisions. These include the level of harm/risk that will trigger the precautionary principle, as well as which data is needed by the producer to satisfy the precautionary principle, and how benefits can be weighed against risk (Marchant, 2003).

Table 5.5. Nanotechnology Precautionary Principle Limitations.

The precautionary principle needs guidelines or criteria to resolve these questions, and arguably from well informed expert decision-makers within the legal nanotechnology paradigm. Without these, it can be used for mischief making (Marchant and Mossman, 2004) and can also suffer from being '*biased*

towards the status quo'. This has the potential to impede new technologies, even those that may prove beneficial (Cross, 1996; Holm and Harris, 1999).

The precautionary principle may be particularly beneficial where there is uncertainty, resulting in challenges to determine risk, and develop a 'fit-for-purpose' risk assessment. Where there is uncertainty, it can move to shift the burden of proof from needing scientific evidence, which due to potential limitations in testing could be used to reduce the impact of a product suspected of potentially causing unacceptable harm. Importantly, the precautionary principle cannot necessarily make anything safe, but more mitigate the risk from it. More than this it can encourage R&D into alternative 'safer' technologies, but as might be expected can be open to abuse to limit commercialisation of products, based more on psychological concerns than scientific fact.

Given that nanotechnology offers many potential environmental and human health benefits, there are drivers to promote this technology rather than hindering it, as long as risk can be mitigated and adequately managed. However, as with any promising technology with associated risk, and according to Sunstein (2003), the precautionary principle does not provide sufficient guidance on which direction to choose i.e. risk or benefit. Wiedermann and Shutz (2005) have also argued that the precautionary principle actually increases the concerns of the public rather than addressing it, therefore creating a greater anxiety about this technology (Wiedermann and Shutz, 2005). This is because it alerts the public that there is potential risk, which is often sensationalised by the media creating a negative perception and unease.

The examination in this section so far suggests that neither the precautionary principle nor traditional risk management approaches provide sufficient strategies for mitigating risk. Technologies in the past have had their risk regulation postponed until proof of evidence could be confirmed (Wilson, 2006; Florini *et al*, 2006; Lin, 2007). Other risk management tools such as liability, self-regulation, and risk communication can be used as an interim measure (Baram, 1984; IRGC, 2006). With this in mind, it is not surprising therefore that nanotechnology is still relatively unregulated with numerous governments

showing concern about regulating nanotechnology products as nanotechnology products (Bowman and Hodge, 2007). With the demonstration that the current models of anticipatory regulation appear to be ill advised and inappropriate, it does not mean that there are not substantive drivers for pursuing regulation. Arguably, it is inevitable that nanotechnology will eventually be regulated and this could be brought about by public and/or political pressure, necessitating a regulatory response (Marchant and Sylvester, 2006) or due to economic, environmental or ethical concerns. As a way of dealing with this challenge, the next section considers a new risk management model.

5.2.6. A New Risk Management Model

There are many challenges facing the management of risks concerning nanotechnology. The risk management models that are currently in place, including the precautionary principle are arguably not sufficient in their present state for nanotechnology. There is an urgency to develop a successful risk management strategy so that commercialisation of nanotechnology can go ahead safely and at a rapid pace, where risk is more adequately considered against potential benefits.

Suggestions have been made that any new risk management model should incorporate a flexible and evolutionary approach towards nanotechnology regulation (Marchant, 2003). Coupled with this it should draw on a range of different stakeholders to better inform decision-making. Within such a framework, some scholars have argued that a 'soft law' approach that is 'non–traditional' should be implemented giving an incremental and reflexive management of nanotechnology risks (Forrest, 1998; Fiedler and Reynolds, 1994; Reynolds, 2003; Wejnert, 2004; Segal, 2004; Bowman and Hodge, 2007; Breggin and Carothers, 2006; Paddock, 2006; Wilson, 2006; Lin, 2007; Bowman and Hodge, 2007; Kuzma, 2007). Drawing on the participation of public and private stakeholders, as well as researchers and those already commercialising nanotechnology, would enable a 'greater voice' to be heard that may more closely mirror the reality of these products. It would also have the potential to

assist in gaining a clearer understanding of benefits or risks of any particular nanotechnology product or process and thus communicating that understanding to the public, and regulators enabling multiple risk aspects to be managed. Through experience iterative procedures can allow the gradual development of cost effective and appropriate regulatory systems, Marchant *et al* (2008: 23) argues that this approach is the best way forward as it takes into account most of the major issues.

Risk is problematic when dealing with nanotechnology, as at present it is inherently uncertain. There are potential risks in the areas of environment, health and safety threshold levels of exposure, as well as variations amongst processes and products that are closely related. The heuristics influencing the individual view of risk cannot easily be negated but transparency and dissemination of all risk information as it becomes available, can create a higher level of trust by individuals who are responsible for nanotechnology's development.

When examining traditional approaches to risk regulation, they may appear inappropriate for nanotechnology due to the reasons discussed previously. According to Marchant *et al* (2008: 4) Ayres and Braithwaite's *Responsive Regulation* (1992) provides a comprehensive theoretical approach arguing that the choice given is between '*regulation*' and *'deregulation'* stating that regulation involves a relationship that is symbiotic between private and public actions that are able to be managed and can respond to variations in behaviour and conditions in industry that will obtain a better regulatory outcome. It could be argued with such rapid rates of R&D and manufacturing of nanotechnology products, that strategy is needed that will reduce any potential risks, even if they are merely perceived.

Finally, any new risk management strategy should encompass the challenge of stipulative and lexical definitions, which echo into the most basic question of '*what is nanotechnology?*' (Marchant *et al*, 2008: 23) or more pertinently for this study, '*what is a nanoparticle?*' These points lead to more uncertainty, hampering efforts in identification of risks linked to the research, technologies and application process. Even with this uncertainty surrounding nanotechnology

as political pressure continues to grow, the need for a regulatory response becomes essential for the future.

After discussing many elements of risk, the next section moves onto explore insurance as it relates to high technology and particularly nanotechnology risk.

5.3. Insurance

As detailed in the prior part of this chapter on nanoparticle risk, there are numerous commercial drivers for high technology product insurance, for multiple stakeholders. As a starting point, it is perhaps most helpful to examine what is meant by insurance. There is a 'long' history attached to insurance, with the foundations being within the practices adopted by Italian merchants from the fourteenth century, although it is likely that insurance practices existed before that time. While a thorough examination of the foundations of insurance are beyond the remit of this study, it is worth briefly stating that many of the principles developed for maritime insurance have been adopted for more modern insurance endeavours. At present it is possible to insure almost every conceivable event or thing, against risk of loss or damage through first and/or third party insurance (Birds, 2013). Although the term insurance is commonly spoken about, defining the phenomenon from a legal standpoint is problematic (Purves [2001] J.B.L 623). The statutes dealing with the regulation of business insurance do not contain a definition of insurance, as there is a perception that any attempt to define might misconstruct the phenomenon of insurance and may produce negative consequences for insurance contracts. Within itself, this is an important aspect but more generally is an important aspect for the construction of any definition, its perceived meaning(s) and wider echoes into the practice of law. Birds (2013: 9) however argued that:

> '*It is suggested that a contract of insurance is any contract having as its principle object* (*Re Digital Satellite Warranty Cover Ltd* [2011] EWHC 122 (Ch) at {84} to {86}) *one party (the insurer) assuming the risk of an uncertain event* (*Gould v Curtis* [1913] 3 K.B. 84),

which is not within its control, happening at a further time, in which event the other party (the insured) has an interest, and under which contract the insurer is bound to pay money or provide its equivalent if the uncertain event occurs'.

More simply however and drawing on a lexical definition from the Oxford English Dictionary (2014: WP) the definition of insurance is:

'*An arrangement by which a company or the state undertakes to provide a guarantee of compensation for specified loss, damage, illness, or death in return for payment of a specified premium*'.

Investor Words 2510 Insurance (2014: WP), utilised a descriptive definition of insurance as:

'*A promise of compensation for specific potential future losses in exchange for a periodic payment. Insurance is designed to protect the financial well–being of an individual, company or entity in the case of unexpected loss. Some forms of insurance are required by law, while others are optional. Agreeing to the terms of an insurance policy creates a contract between the insured and the insurer. In exchange for payments from the insured (called premiums), the insurer agrees to pay the policyholder a sum of money upon the occurrence of a specific event. In most cases, the policyholder pays part of the loss (called the deductible), and the insurer pays the rest. Examples include car insurance, health insurance, disability insurance, life insurance and business insurance*'.

Within the practice of insurance law, are several requirements for something to be insured as detailed in Table 5.6.

Requirement	Meaning
Legal entitlement	There must be a legally binding contract where the insurer must be bound to pay.
Uncertainty	There must be uncertainty to whether the event being insured will occur, as opposed to life insurance when the uncertainty is when.
Insurable interest	The insured party must have an interest in the thing insured.
Control	The uncertainty related to the thing being insured must be outside of the control of the insurer, although this has not been directly considered.
Payment does not have to be money	The insurer does not need to be obligated to pay money.
Stipulated premium and policy	The provision of a clearly stipulated premium and policy has been argued as being necessary.
Utmost good faith	The party seeking insurance must act in the utmost good faith for the insurance policy to be valid.

Table 5.6. Requirements for Insurance.

As might be expected, these requirements will have different levels of importance for different elements being insured, but can be taken as a foundation for setting an insurance contract. In the following section and moving on to examine insurance in this study, companies engaged with nanotechnology insurance are examined.

5.3.1. Companies Engaged with Nanotechnology Insurance

The integration of nanotechnology into an insurance framework has proved challenging and is an on going process, with much debate at how it should be carried out. Embedded within an insurance perspective, there is a composite mixture of overt and unknown risk associated with the use of nanomaterials creating many challenges for how companies wanting insurance and those providing insurance should proceed. Some of these insurance difficulties are

based within risks associated with (1) employers liability, (2) product liability, (3) environmental impairment, and (4) directors' and officers' liability.

As a starting point and at present, the majority of commercial insurance policies do not mention or contain any kind of definition of nanoproducts. Some companies such as Continental Western Group are actively trying to exclude losses that are related to nanoproducts, and in particular CNTs, as they can be linked being similar in nature to asbestos. With growing debates surrounding nanotechnology, Lloyd's of London (Baxter, 2008) has hypothesised several possible risk scenarios as shown in Table 5.7.

Risk Scenario	Details
Pollution spill	Potentially caused by spills or leaks at a nanomaterial production facility.
Chronic illness	Workers and/or end-users developing chronic illness from nanoparticle exposure.
Nanoparticle accumulation	Nanoparticle leaching into the environment, resulting in increased levels over time.
Future findings	Development of new techniques and equipment that may find problems in materials currently not assessed or deemed safe.
Incorrect analysis	Intentional or unintentional incorrect analysis producing results suggesting dangerous products are safe.

Table 5.7. Potential nanoparticle risk scenarios.

As was stated by Lloyd's of London (Baxter, 2008: WP).

> '*The insurer can accept that nanotechnology risks are included within the overall set of risks that the insurance policy covers and therefore may not need to mention nanotechnology specifically. The additional risk introduced is then reflected in the price of premium for the insurance*'.

The insurance company Allianz claim that they are insuring many commercial and industrial clients from the arena of nanotechnology (Allianz, 2014). This ranges from manufacturers of consumer products to chemical companies producing nanoparticles. As their insurance portfolios grow, an increasing number will contain policies associated with commercial activities relating to nanotechnologies. This would suggest that the insurance industry is therefore contributing to an early commercial phase of nanotechnology. Adequate insurance coverage is paramount particularly for SMEs who wish to engage in commercial and entrepreneurial activity. According to Allianz (2014: WP): '*A balance needs to be kept between managing a sustainable insurance portfolio with adequate returns and maintaining a responsible approach towards economic development.'* The insurance industry, *'in its risk carrying capacity, is always an enabler of new technologies*'. Allianz have stated that '*currently, there are no specific policy exclusions or terms in regular use that are tailored to address risks from nanotechnologies*' (Allianz, 2005). GenRe states, *'today most nanotechnology risks are written on 'occurrence policies.'* These are commercial general liability policies (Allianz, 2005: WP). By not excluding nanotechnologies from their policies, Allianz are promoting that nanotechnologies are not risk laden or a 'special case.' In other words, until nanotechnologies are proven to be hazardous they are not treated as such therefore the burden of proof lies with the science companies to prove risk or with regulators to provide regulations for nanotechnology companies to work inside. Problems will occur if nanoparticles are acknowledged as being different to their bulk state and potential toxicities surrounding their physicalities are proven. This could have serious affects on insurance policies by raising premiums, or by insurance companies refusing to insure products that contain nanomaterials. Many SMEs could also be affected due to increased premiums rendering them unable to continue to produce or sell products containing nanoparticles. As manufacturers of nanoparticle products are liable for any health, safety or environmental issues or damage caused by their products, it should be mandatory for all companies to take out adequate insurance. This could be problematic when dealing with nanoparticle products, as many of the risks are unknown due to lack of data surrounding nanotechnology. Therefore I would suggest that it should be a prerequisite of any company manufacturing

nanoparticle products that they not only insure their products but also insure their employees as it has been suggested that nanoparticle toxicity has the potential to cause chronic illnesses in the long term (Marchant, 2008).

Lloyd's of London stated that nanoparticle toxicity *'could impact on a suite of liability covers'* and that risks from nanotechnology have the potential to require the insurer to pay for a host of different aspects. These aspects have been summarised in Table 5.8

Number	Insurer requirement
1	Clean up costs of land and water contamination.
2	Medical costs of treatment of human exposure.
3	Liability claims from persons directly affected, environmental groups and shareholders.
4	Latent liability claims of persons affected.
5	Business interruption while facility is investigated.
6	Cost of product retail.

Table 5.8. Potential insurer cost requirements

This section has highlighted some of the challenges of nanotechnology insurance, but a more fundamental claim can be made towards the challenge, which is discussed in the following section of research paucity and insurance.

5.3.2. Research Paucity and Insurance

There has been a lack of a coherent research strategy to understand the risks facing businesses engaged with nanotechnology commercialisation, which echoes into the challenges facing insurance. A major concern about nanoparticles is their toxicity, which can be variable and difficult to determine. Auty (2014: WP) stated that:

> '*The risks associated with nanoparticles are not well known outside of specialist sciences and this is a problem. Most people have an*

intuitive sense of risk, based on precedent, analogy, trusted sources and meaning. With engineered nanomaterials, there is little meaningful precedence, and trusted sources are hard to find. Regulators, insurers and other risk managers are thus unable to produce simple generally applicable messages on engineered nanomaterial risk'.

A further difficulty is that many products and processes include nanoparticles without the knowledge of the producer or the user. This leads to a major problem of causality and what a company seeking insurance can report in good faith. There are no standardised common reporting documents identifying the exact type of nanoparticle contained in each product, which is a critical aspect to weighing up a risk, as there is insufficient knowledge to determine effective controls. This is something that regulation should address, as there are thousands of products on the market containing nanoparticles with the potential to be hazardous. A standardised common reporting document or checklist should be created for manufacturers/producers/importers, which could be handed to an insurer, allowing for more transparency when assessing risk. While this may mean that companies seeking insurance act in good faith in reporting what they know, this might result in insurance companies not wanting to insure. Further to this, with nanotechnology being such a highly specialised field, it raises challenges for communication of technological aspects about products and understanding taken away by the insurer and insured. Arguably more research is needed into risks pertaining to nanomaterials and the controls necessary to reduce potential risks to public health and to the environment. According to Auty (2014: WP):

'*My biggest concern is retrospective risk, closely followed by rapidly changing risk….Engineered nanomaterial use is very widespread and the risks largely unknown. At some point a loss will be identified and the change in liability exposure resulting from this change in knowledge could be very significant. With rapidly changing risk, you could go from 'possible' to 'plausible' to probable' with a couple of years and implied liability exposure goes from none to maximum in*

the same time scale. Risk management measures may find it hard to keep up. Of particular interest under rapidly changing risk are carbon nanotubes and silica'.

Traditional laws that govern compensation and liability are based on a *'one-to-one assignment of injury and damaging agent.'* It may be extremely difficult to clarify whether the exposure to nanoparticles is the cause or a contributing cause to an illness. Experts in industry as well as insurers, are having to tread carefully due to the potentially adverse effects on human health, which could be caused by a wide variety of products containing nanomaterials, such as cosmetics, lubricants and fuels, construction materials, surgical implants, pharmaceuticals, food ingredients and food wrappings. Binion (2008: WP) stated that:

'*In 2006, one alleged 'nano' product was subject to recall after reports of users suffering breathing problems, some requiring hospitalisation. While it was subsequently determined this product did not incorporate true nanoparticles or nanotechnology, insurers should take heed of the fact that plaintiffs' attorneys are already rallying round a potential new source of tort claims and plaintiffs*'.

There is also the impact of nanotechnology on the environment where there is a continued debate regarding the extent that commercial and industrial use of nanomaterials has on the affect of organisms and ecosystems. When examining the risks, it is easy to see why nanotechnology has been compared to asbestos, welding fumes and silica, and has the potential to become a source of *'a new mass toxic tort'* (Binion, 2008).

It has been argued that so far the insurance industry is becoming aware of the risks associated to nanotechnology, but until the risks manifest themselves through thorough risk assessment demonstrating actual harm caused, insurance for that harm may not be possible (Binion, 2008). As Marchant *et al* (2008: WP) stated: '*Underwriters and risk experts at Zurich will be monitoring this area with keen interest but for brokers, for now it's a watching brief*'. The next section therefore examines underwriting and nanotechnology.

5.3.3. Underwriting and Nanotechnology

Underwriting is the process and end point where an insurer, signs and accepts liability, along with payment should loss or damage occur to a contractually bound insured party. Within underwriting, one of the greatest challenges facing nanotechnology insurance is the lack of definition, or highly variable definition of nanotechnology. While there are common and lexical definitions, they are often too broad and can capture 'almost anything', and have created a problem for insurers for where to draw demarcation points. Importantly, insurers have not sought to create a definition, and have relied on other, non-uniform sources. At the present time (2015), nanotechnology from a scientific perspective is a blanket term used to cover the manipulation of matter with at least one dimension sized from 1–100 nanometres (Royal Society and Royal Academy of Engineering, 2004). With so much potential variability between what this might mean (see section 2.3.1), insuring is not without challenge, as mischievous or unintended linguistic constructions may miss the physicality of nanotechnology. Ideally, specific enquiries and disclosures of size and nature of the material, plus any processes involved are necessary for the underwriting to be more effective and fit-for-purpose.

There is difficulty when predicting the influence that nanotechnology will have on the tort system. Any effect could have subsequent effects on insurers and policy–holders with the potential to bring significant problems if coverage litigation occurs. For example, if nanomaterials are involved in a coverage issue, determining exactly when the injury or damage occurred and by whom (if appropriate) and also if it occurred during the policy period. The Swiss Reinsurance Company have predicted that, *'nanotechnology related injuries are likely to be chronic, rather than acute, with periods of latency before manifestation'* (Binion, 2008). Therefore trigger issues – those that initially cause the damage/injury, will be the greatest cause for concern by the policy holders who will be seeking coverage for any 'nano' related claims. Due to the large numbers of nanomaterials currently being used in an array of products, insurers

may find that they become involved in an insurance battle, trying to prove the initial trigger to the damage/injury.

Currently the language used in a standard nanotechnology policy excludes coverage for property damage and bodily injury, *'expected or intended from the standpoint of the insured'* (Binion, 2008: WP). The legal standard can vary from authority to authority but with the current lack of research into the safety and risks of nanomaterials, insurers may find it difficult to win a nanotechnology tort claim. The major problem for any claimant would be, with the large amount of products containing nanomaterials, which single product caused the damage/injury or was it a collective issue, where each nanomaterial is said to be safe but mixed together can cause a damaging effect (Binion, 2008).

According to Binion (2008: WP), there is an exclusion policy for coverage of '*'bodily injury' or 'property damage' arising out of the actual, alleged or threatened discharge, dispersal, seepage, migration, release or escape of 'pollutants'[.]*' Binion (2008) describes a '*pollutant*' as *'any solid, liquid, gaseous or thermal irritant or contaminant, including smoke, vapor, soot, fumes, acids, alkalis, chemicals and waste*'. For example, in the following scenario, an individual uses a body cream that contains fullerenes, which in this case has not been classed as a traditional pollutant (this is what the exclusion is meant to apply to). The company defending the claim would likely argue that any '*bodily injury'* or '*environmental damage'* from normal usage of the product was not caused from *'release or escape'* of any pollutant. Whereas the insurer is more likely to claim that the damage/injury was caused from waste, which is subject to the pollution exclusion. In both instances, the pollution exclusion could be applied, demonstrating difficulties when dealing with this emerging technology (*Am. States Ins. Co. v. Koloms*, 1997).

Another problem that arises concerning exclusion is that of coverage for property damage. Standard CGL (commercial general liability) policies exclude coverage for property damage to the policy holder's *'work'* and *'product.'* The definition of *'your product'* is:

'*any goods or products ... manufactured, sold, handled, distributed or disposed of by the policyholder and the containers and the materials, furnished in connection with such goods and products*'.

The definition of '*your work'* refers to *'work or operations'* that are performed by the policyholder or on his behalf. This also includes any materials used in connection with this work. A company could argue that neither of the two exclusions would apply, stating that bodily injury and property damage claims do not reflect or constitute damage to their product or work (Binion, 2008). Again lack of information on nanotechnology risks influences CGL policies (Binion, 2008: WP).

'Due to the lack of clear information on nanotechnology risks, the risk of significant third – party claims for bodily injury or property damage, and the fact that the current standard CGL policy terms might not account for nanotechnology – related claims, insurers should consider the options available to them now for effective risk control'.

The Swiss Reinsurance Company (2007) suggest that some policies that are claims based should be restricted until the risks of nanotechnology are more clearly identified. Also it may be necessary for insurers to consider excluding individual products until nanotechnology has more fit-for-purpose regulation and the risks are more fully understood. If exclusion were to be made, then an extensive disclosure would be necessary about the product and the nanotechnology used and any nanomaterials contained in the product. All dangers and risks must be researched and documented meticulously making exclusions increasingly more complicated. Problematically however, Auty (2014: WP) from Liability (Oxford) Ltd. claimed that, *'risk management measures which should be adequate for one engineered nanomaterial may not be adequate for even a trace of another'*.

There are many unquantifiable risks when looking at nanomaterials from an insurance perspective, as many risks may not be apparent. Lloyd's of London

(2007: WP) claim in a paper describing options that insurers face when dealing with nanotechnology risks:

> *'the insurer can accept that nanotechnology risks are included with the overall set of risks that the insurance policy covers and therefore may not need to mention nanotechnology specifically. The additional risk introduced is then reflected in the price of premium for the insurance'*.

There are different types of policy, which can cover risks involving nanotechnologies. In a policy known as an *'all–risk'* policy, nanoparticle products do not have to be listed by the insured to be covered. According to Re Katrina Canal Breaches Litigation (2007: WP), this type of policy:

> *'extends to risks not usually covered under other insurance, recovery under an all – risk policy will be allowed for all fortuitous losses not resulting from misconduct or fraud, unless the policy contains a specific provision expressly excluding the loss from coverage'*.

This type of policy only necessitates the policy-holder to show loss or damage to the property that is covered, meeting any responsibility needed to demonstrate coverage, while the insurer must prove exclusion against any of the insured's losses (Int'l Multifoods Corp. v. Commercial Union Ins. Co, 2002).

It has been argued that insurers like to focus on a common exclusion. This is often the pollution exclusion where all–risk and named–risk policies in standard - form property policies profess to exclude all losses that are caused by, *'discharge, dispersal, seepage, migration, release or escape of 'pollutants''* (Insurance Services Office, 1990). In this case a *'pollutant'* is defined as *'any solid, liquid, gaseous, or thermal irritant or contaminant, including smoke, vapour, soot, fumes, acids, alkalis, chemical and waste*' (Insurance Services Office, 1990: WP). Nanoproducts do not fit in with any of the above listed items (although soot contains natural nanoparticles) but insurers may argue that they are *'contaminants'* or *'irritants.'* These terms are not usually explicitly defined in

insurance policies therefore courts typically rely on definitions that are set out in dictionaries (Werbach, 1994). Yet, nanoparticles contained in products have the potential to be *'irritants'* or *'contaminants.'* The problem lies with the insurer to prove that the nanoparticle fits within the description and definition of *'irritant'* or *'contaminant.'* In many cases courts will limit pollution exclusions to conventional *'environmental pollution'* (Carpenter and Zeng, 2015). The reason for this is because the term *'irritant'* could then be extended to include common dust as a pollutant (Parks Real Estate Purchasing Group v. St. Paul Fire and Marine Ins. Co, 2006). The common pollution exclusion is a point for debate as it is not broad enough to encompass nanoparticles. This argument is supported by the presence of a separate exclusion policy for the majority of modern properties. This is following losses that were incurred from asbestos after courts maintained that asbestos was *'not'* a pollutant. When examining a Commercial General Liability (CGL) policy, a policyholder must demonstrate that losses suffered are based on liability for bodily injury or property damage which has been caused by an '*occurrence*'. A typical definition of an *'occurrence'* is *'an accident, including continuous or repeated exposure to substantially the same harmful conditions'* (Lloyd's, 2007). Insurers are likely to dispute the pollution exclusions in CGL policies, arguing that they prohibit coverage for any losses that have been caused by nanoproducts. The language used for the standard pollution exclusion which is contained in the CGL policies is very similar to that of other CGL policies in that it applies to *'actual, alleged or threatened discharge, dispersal, seepage, migration, release or escape of pollutants'* as well as having the same definition of the word *'pollutant.'* (Kimber Petroleum Corp. v. Travellers Indem.Co, 1997).

5.3.4. Commercial Insurance Coverage

The challenges that nanotechnology bring to the commercial world of insurance are not small, particularly for whether nanoparticles should be or are covered by insurance. While the problem of how to insure products that have potential health risks and uncertain exposure rates is not new to insurance law (Hull and Bowman, 2010) the complexity, uncertainty and opacity related to nanotechnology

arguably is. More simply put, it is difficult to find a collection of products that in any way mirror the potential challenges that nanotechnology displays. Looking for how to deal with this, Blaunstein (2006) believes that insurance coverage for nanotechnology issues will occur in three phases, as shown in Table 5.9.

Phase	Description
1	A period where nanotechnology is studied and risks and exposures assessed. These potential risks are covered within existing policies with no separate definition.
2	An apprehensive period where the insurance industry may attempt a reduction in coverage exposure.
3	The final period where insurance companies may offer customised and specialised solutions for nanotechnology coverage.

Table 5.9. The three predicted stages of nanotechnology insurance.

Blaunstein (2006) believes that currently we are in the first phase, with an unknown timescale existing for the move into the following second and third stage. While in the first stage, Lloyd's of London in 2008 claimed that insurers of nanotechnology products have several options when issuing commercial insurance coverage (Baxter, 2008). They noted that complete exclusion of nanotechnology products by insurers could be undertaken, or a separate limited coverage for nanotechnology risks with full coverage for other aspects of the policy, or insurers may only allow a fixed period of time where claims can be accepted after the policy has been written. Lloyd's also noted that they as an insurance group will continue to research and monitor any potential risks linked to nanomaterials, taking a 'wait and see' view on the situation (Germano, 2008).

Continental Western Insurance Group was the first insurance company in the US in 2008, to issue a *'nano –specific commercial insurance exclusion*' (Hull and Bowman, 2008: 305). Monica (2008, in Hull and Bowman, 2008: 305) explained that:

> *'The intent of this exclusion is to remove coverage for the, as of yet, unknown and unknowable risks created by – products and processes*

that involves nanotubes. The exclusion is being added to make you and your customers explicitly aware of our intent not to cover injury and / or damage arising from nanotubes, as used in products and processes'.

The reasoning behind this decision was due to the comparison of carbon nanotubes to asbestos. Continental made a specific exclusion covering (Monica, 2008; in Hull and Bowman, 2008: 305):

'*bodily injury, property damage, and personal and advertising injury related to the exposure of nanotubes and nanotechnology in any form. This includes the use of, contact with, existence of, presence of, proliferation of, discharge of, dispersal of, seepage of, migration of, release of, escape of, or exposure to nanotubes or nanotechnology'.*

It is not known whether Continental Western Insurance Group have actually implemented this exclusion as these documents were hastily removed from Continental's website on the publication of an article by the BNA which discussed nano specific exclusion. As with much of nanotechnology, this potentially creates further difficulties for decision-making within insurance law. Thus, the following section considers the future of insurance and nanotechnology.

5.3.5. The Future of Insurance and Nanotechnology

At present, most insurance policies do not explicitly exclude nanomaterial risks, which raises the question of whether current policies cover nanotechnology, or whether they are excluded? The opinion over whether there will be a nanotechnology exclusion policy is not agreed on, as Lloyd's (2007: WP) claimed that:

'*Insurers could, theoretically exclude any liability related to losses caused directly by nanotechnology. As long as exclusions are well*

worded and enforceable this reduces the risk to the insurer to near zero…'

However, Allianz and OECD (2010: WP) wrote: *'it seems neither feasible nor appropriate to start a debate about a general exclusion of nanotechnologies from the commercial and industrial insurance products and applications'*. If there is to be no debate as suggested by Allianz and OECD, perhaps this suggests a move for insurers to outline their exclusions and coverage in a 'new' language that is applicable to nanotechnology within regulations and statutes so that there is no confusion about coverage or exclusion. Although this type of regulation is still in its infancy, insurers still need to link their definitions and coverage to governmental definitions and regulations. Policyholders must also work alongside the insurance brokers by paying attention to exclusions and coverage limitations particularly at the time of policy renewal. This may mean that insurers may increase specialized coverage once there has been better assessment of risks regarding nanotechnology. This would come with an increased premium. If these policies mirror other specialised policies that are already in place, they would most likely be single risk coverage that would provide low coverage limits but would demand a high premium.

Finding out potential risks from nanotechnology may bring a higher cost per premium for a company wanting insurance as well as potentially creating other problems. For those companies that invest in safety testing and monitoring, they may find that they have become liable for risks to the environment, health and human safety through that testing. To be unaware of the risks from a lack of company research would mean that the company would avoid liability. Therefore there is a suggestion that companies would avoid testing for risks to avoid liability (Wagner, 2008).

5.3.6. Possible Future Insurance Scenarios

It is difficult to predict how insurance coverage will evolve for nanotechnology and nanoparticle products and whether it will be in a similar way to other

emerging technologies. Broadly speaking and according to Hull and Bowman (2008), there are three phases that insurance coverage evolves through, which include (1) the early study phase, (2) the fear phase, and (3) the mature phase. Hull and Bowman (2008: 175) argued that the first phase, which is the early study phase:

> '*typifies the current state of nanotechnology, is characterised by continuance of existing policy coverages and efforts by insurers and reinsurers to become more familiar with those special exposures and risks posed by nanotechnology*'

Initially underwriters may make a positive response to applications due to increased premiums for such technologies, but as there are no verified risks, there is no definitive decision to exclude nanomaterial coverage from policies. Hull and Bowman (2010) have stated their reasons that this strategy may be adopted including, a minimal risk of exposure to the public, a variety of different nanoparticle properties and products with different risk potentials, and the zeitgeist of insurance portfolios, where the diverse nature of technologies and unfavourable single effects of products are considered.

Presently there is a lack of data validating risks associated with nanomaterials and nanotechnologies, but with global efforts by governments to seek information on health, safety and the environment (HSE), insurance companies need to be vigilant when creating policies that cover nanotechnologies and products containing nanomaterials. In the UK, The National Industries Association (NIA) is attempting to develop a roadmap, which will set out Responsible Technology Development, in order to set out a programme for health, governance and the environment (Hull and Bowman, 2010). Once an improved and stable regulatory landscape has been devised, insurers will have a clearer vision of any potential risk.

Insurers are also collecting information themselves concerning risks pertaining to nanotechnologies and nanomaterials. This information includes how businesses that are involved with nanotechnologies dispose of, store or produce

nanomaterials. Insurance companies are assessing any potential bodily injury to the public or workers, property damage, or environmental damage or liabilities associated with businesses using or handling nanomaterials (Hull and Bowman, 2010).

The second phase, which is the 'fear' phase, occurs when there is increasing anxiety about any future liability. The suggestion that carbon nanotubes behave in a similar way to asbestos coupled with other suggestions to stop the progress of nanoscale research, indicate that this phase has already arrived or if not is imminent (Poland *et al,* 2008; ETC Group, 2003). Insurance companies alongside reinsurers have already begun to believe that the risks associated with nanotechnologies might be greater than anticipated. With increasing media coverage, doubts are beginning to be raised within insurance companies about current policies causing them to reconsider coverage and limits. The *'fear'* stage may be unpredictable as there are conflicting research results which are being published on a daily basis. If insurers decide that the risks are too great, they will pull out of the market altogether leaving companies to 'insure themselves.' If this scenario were to take place, it is possible that governments, who want to push forward the positives of nanotechnology, may propose alternate solutions for high-risk activities connected with nanotechnology.

One of these solutions could involve the initialisation of pools of insurance companies who take on the most unpredictable aspects of this technology. It would be mutualised and the funding exposure balanced across companies insured for nanotechnology, therefore allowing premiums to be lower (Hull and Bowman, 2010).

Another solution may be for governments to step in, backing up any liability on the part of the nanotechnology industry. There is precedent for this in the US when Congress enacted the 1957 Price Anderson Act, limiting the liability *'of the nuclear industry in the event of a nuclear accident in the United States'* (Hull and Bowman, 2010: WP). Further to this, Hull and Bowman (2010: WP) suggested that insurers might need:

> *'to establish a no – fault system in which the nanotechnology industry funds the first layer of insurance according to a predetermined scheme and any claims above that amount would be covered by national government'.*

This type of regulation can be seen as rigid, slow, cumbersome and incurring high costs (Moran, 1995; Sinclair, 1997). Although due to their compulsory nature, and strong accountability they possess characteristics that appeal to voters. Ludlow *et al.,* (2009; In Hull and Bowman, 2008: 316) have suggested that:

> *'clear and consistent state – based regulation provides many advantages compared with no regulation. In many instances industry prefers this form of regulation because it provides a level playing field, as well as providing protection against short – cutting competitors. It also provides certainty, assisting in securing capital finance and insurance'.*

The third phase, the '*mature*' phase is when insurers know the exact type, severity and frequency of losses that could occur as a result of nanotechnologies. Insurers will be able to predict with more accuracy the types of losses due to more information being readily available from research, allowing for a better understanding of potential risks. Customised solutions at reasonable rates should therefore become available.

It is necessary for governments, the legal community, manufacturers and scientists to work together to quantify and identify nanotechnology risks. Both the legal climate and public response are critical for this industry to continue to be healthy but this is under pinned by the accuracy of risk related data provided (Hull and Bowman, 2010).

After examining multiple aspects of nanoparticle risks and insurance' the next section draws multiple aspects together in a summary.

5.4. Summary

This chapter has examined nanotechnology and particular nanoparticle risk and insurance. While the arenas of risk and insurance have frequently dealt with complex, uncertain and opaque products, the speed, technological complexity and opacity of nanotechnology products have created an unprecedented challenge. Coupled with a paucity of scientific data to back up claims being made about the risk and safety of nanotechnology and nanoparticle products, it is unlikely that a fit-for-purpose solution will be found that meets all stakeholder criteria. The examination of nanotechnology products is often linked to concerns about prior products that 'failed'. Thus, the shadow of the past for prior technologies such as asbestos has been argued as creating a shadow over the future for nanotechnology products such as CNTs, which has impacted on both risk and insurance of products. It is suggested that the complexity and paucity of technical data for nanoparticle products is hindering more adequate assessments of risk and insurance for specific concerns, and that this factor must be a priority for these areas to advance in a meaningful way. Without meaningful data, it will be difficult to use many of the risk assessment systems, in turn creating challenges for insuring products. Through physical scrutiny of these products, there is a potential for nanoparticle products to be assessed as their own entities, and limit socially constructed arguments being made from prior technologies.

It would seem prudent that an approach is taken to facilitate the collection of 'fit-for-purpose' physical data with a compilation into an industry database. The collection and utilisation of this data, although itself potentially problematic, has the potential to enable more appropriate risk based calculations and decisions. Practically, the construction of perceived and actual risks must be in conjunction with key stakeholders who have a high level understanding of the physicality of these materials and products, as well as limitations of testing methodologies and how this relates to risk. Thus, the suggestion at this point is not necessarily to state how nanoparticles should be regulated, but more to indicate a roadmap to enable regulation of risk.

The next chapter goes on to look at health, safety and the environment, which is an area often debated and contested for the impact that nanotechnology and nanoparticles will have, as well as the potential for regulation.

Chapter 6. Health, Safety and the Environment.

6.1. Introduction

This chapter is broadly driven by the research question 'What are the health, safety and environmental implications of nanoparticle products, and how might regulation be used to address this issue?' Nanotechnology products exist within an arena of commercial promise and inherent risk. Underlying many concerns about risk is the aspect of health, safety and the environment, which this chapter examines. Aspects concerning health, safety and the environment start at product inception, and span through R&D, usage and end with disposal. Engaging with this regulatory journey, this chapter explores issues including the concept of health, safety and the environment in different contexts, difficulties with addressing and regulating health, safety and the environment and regulation as a commercial barrier.

With any examination of health, safety and the environment is the way in which a product may create harm, and which for simplicity is split into two forms. The first is the harm that may come from a product being used intentionally/unintentionally and resulting in harm to the user, others or the environment, which at some level can be controlled by a user. The second, which is much harder to control, is the unintended exposure to others, and for example, silver nanoparticles being washed out of clothing into drinking water, which many people are potentially exposed to. The examination of health, safety and the environment is therefore a complex mix, and often with great difficulties to unpick the important underlying aspects most pertinent for regulation. As a starting point to set up the rest of this chapter, the following section considers the concept of health and safety.

6.2. The Concept of Health and Safety

Health and safety is a much-discussed aspect of personal and organisational life, with regulation being a vehicle to engage with a multitude of often-conflicting drivers. While there is a growing background narrative about challenges facing health and safety (HSE, 2014) it has been argued that there are very real needs to better regulate aspects of high technologies such as nanotechnology to reduce risk for the individual, society and the environment etc. (HSE, 1974). In the UK for example, the main regulatory body driving this goal is the Health and Safety Executive (HSE), which has the mission via '*regulations and procedures intended to prevent accident or injury in workplaces or public environments'* (CompactLaw, 2015: WP). Thus HSE has been involved in the creation of legislation to set in place systems and procedures through regulation to minimise injuries and accidents as well as creating safer environments. This is demonstrated from the HSE statement about workplace safety (HSE, 2014):

> *'All workers have a right to work in places where risks to their health and safety are properly controlled. Health and safety is about stopping you getting hurt at work or ill through work. Your employer is responsible for health and safety but you must help'*.

This is arguably a powerful statement as it sets out that workers have a right for this to be the case, but also creates responsibility for the individual to adhere to workplace systems put in place by the employer. This chapter considers what this means for nanotechnology products in and outside of the workplace. An examination is made of the workplace, due to the availability of numerous legal discourses surrounding nanotechnology. The prevalence of discourse is much higher regarding the workplace, in comparison to personal use, but is often demonstrative of shared challenges arising from nanotechnology.

Looking more at the HSE, it is responsible for regulating, promoting and enforcing health, safety and welfare in the workplace. It also has the responsibility for researching into occupational risks and hazards in England, Scotland and Wales, (Northern Ireland has its own HSE). HSE arose out of the

Health and Safety at Work Act 1974, absorbing the Railway and Factory Inspectorate (although the Railway Inspectorate has since been transferred to the Office of Rail Regulation in April 2006). The Department of Work and Pensions funds HSE, investigating major incidents and industrial accidents, and in 2008, merged with the Health and Safety Commission.

The variety of areas that HSE engages in is vast, including agriculture, construction industries, chemical manufacture and storage industries, and food and drink manufacture, pesticides and recycling and waste management industries amongst others. According to HSE (HSE, 2014: WP):

> *'HSE's role is to ensure that people are protected from any risks to their health and / or safety arising out of work activities, and, HSE, has responsibility for the occupational / worker protection aspect of manufactured nanomaterials'.*

New technologies present potentially unique challenges for HSE, based on the possibility of unique, unusual, and unknowable risks that may arise as technologies are developed and used in the workplace and beyond. Nanoscale materials may react differently to their bulk form and what is known about the characteristics at the bulk may not apply at the nanoscale (as previously discussed in Chapter 3). Not surprisingly, there are many potential health concerns relating to nanomaterials as discussed in this chapter. Importantly though, the HSE has still not actively sought or produced specific regulation concerning nanotechnology. While buried within so many conflicting drivers, it is questionable whether HSE has the 'luxury' of waiting to see what happens with nanotechnology. The approach taken by the HSE is demonstrative of wider discourses that have also argued that it is better to wait and see what happens for nanotechnology products being used by consumers.

In the following section monitoring nanoparticles in the workplace is examined to better understand the dangers from nanoparticles and also challenges for regulating their use.

6.3. Monitoring Nanoparticles in the Workplace

The pervasive nature of nanoparticle commercialisation has resulted in nanoparticle products being used in multiple supply chains and from product use. The wide use of nanoparticles has created risk for potential worker exposure from products containing nanoparticles. It is important that risks should be examined, and where necessary regulatory tools composed and utilised to ensure fit-for-purpose worker and end user protection (Boucher, 2008). It is thus important to examine the life cycle of nanoparticles, from their creation, use and end of life, which can give a fuller view of potential nanoparticle toxicity. This steps away from a propensity for regulations requiring scientific evidence from the R&D stage, and which is often at the expense of monitoring products in more 'real' world environments outside of a laboratory (Hull and Bowman, 2010). Arguments have been made that nanoparticle monitoring should be more orientated towards understanding risks in non-laboratory environments (although in practicality, tested in a laboratory). For example the Parma Declaration on Environment and Health (2010) led to government ministers pledging to implement improved assessment methods to examine health and environmental risks associated with nanoparticles and in a wider context, nanotechnology. The World Health Organisation's (WHO) has also been reviewing relatively recent research to clarify links between nanoparticles and health risks with findings focusing on a more pragmatic approach on risk regulation.

Within any workplace, there are three possible routes where workers may be exposed to nanoparticles, which may also be the same for the end user i.e. the consumer. The three main routes of nanoparticle exposure are (1) ingestion, (2) inhalation, and (3) dermal contact i.e. the skin (Hansen, 2012; Poland, 2012). These routes are all based on an individual coming into physical contact with nanoparticles, with nanoparticles being too small to see with the naked eye. This creates problems for workers, as they will be unable to see the nanoparticles in their environment, potentially creating a false perception of there not being any danger due to exposure, which is again similar for product users. With an increased use of nanoparticles in many work and home places, there is arguably an urgent need to examine the exposure of workers to nanoparticles, as well as

customers, and track this impact over time. Coupled with this is a need to identify worker subgroups that are more vulnerable to nanoparticle exposure, to adequately deal with any associated risk. Although children are unlikely to be within a workplace (unless in a crèche etc.), alongside the elderly they are known to be higher risk groups (WHO, 2008; Chaudhry, 2012). This of course may well be different for consumers, where higher risk classes might specifically use products. Examining the life cycle of a product and associated risk can be beneficial to higher risk groups (as long as this is factored into the examination) as nanoparticles may be specifically utilised in the creation of products for these groups. An example of this is the use of silver nanoparticles, which are beneficial for providing antimicrobial properties for children's products including pacifiers, baby bottles and a variety of other health care products, but may result in greater exposure levels (Chaudhry, 2012).

At present there is a dearth of scientific data for almost every type of nanoparticle, making decision-making for risk within the workplace challenging (Hansen, 2012). For information to be acquired, there is a technical and financial cost of measuring nanoparticles in the workplace, where there appears to be little desired on the part of businesses to carry this out (Hansen, 2012). Although, difficult, this is not a 'new' problem, as The Council for Science and Technology (CST) Nanotechnology have been meeting regularly since 2006 with the HSE to discuss the manufacture, use and disposal of nanoparticles in the workplace. Carrying out accurate and routine measurements has been cited as a current barrier from the CST Secretariat (2006), with problems including, (1) high cost of equipment to carry out routine measurements in workplaces and a (2) lack of skilled operators for such equipment. Stepping beyond this, there is also a third barrier, which is the difficulty of analysis and contextualisation of measured data into a meaningful format on a large scale, where sense can be made to better regulate such environments. Pivotally, there is a lack of equipment to provide accurate monitoring of nanoparticles in complex work places. In an attempt to address this, a Nanoparticle Occupational Safety and Health Consortium (NOSH) led by DuPont (USA) in 2006 set out to look at the specifications required for an instrument that would detect airborne nanoparticles in a working environment. These specifications included the monitoring of each different type

of nanoparticle that an individual would be exposed to, as well as the length of time and dosage of exposure (CST Secretariat, 2006). Although it has been argued that a guaranteed market would exist for any company that could meet those specifications, at present, no such machine capable of all requirements exists (Bosso, 2010). Bosso (2010: xiii) has stated that the U.S. government is spending $1.5 billion annually on nanotechnology R&D but less than 3 percent of this is allotted towards identifying health, safety and environmental issues. Only limited discussions are occurring focussed towards customer use of products, highlighting the challenge facing this area.

The difficulty for any machine to measure workplace exposure is the wide variety of environments that may need examining, where exposure to nanoparticles can occur, which is also the same for customer use, albeit with different environments. Looking at workplace environments, they can include laboratories, transport areas, storage and sales facilities, cleaning areas, waste management and maintenance etc. In any of these or other areas is a possibility for nanoparticles to be liberated into the environment, with potential profound difficulties in measuring their release and effects. Importantly, current safety procedures are insufficient and protection measures inadequate (ETUC, 2008). As a minimum, this demonstrates a necessity for increased training, education and research in health and safety concerning nanoparticles, as well as other nanomaterials (ETUC, 2008).

Examining what occurs when nanoparticles are released into the workplace, either by deliberate action or by leakage, is beneficial to understand the difficulties facing this area. Upon nanoparticle release they will rapidly mix with the air and disperse quickly through the gaseous environment (HSE, 2004). The concentration of nanoparticles does not remain localised, allowing the level of exposure at the site to drop rapidly. This can be demonstrated by the use of nanoparticle aerosols that behave in a different manner to larger particle aerosols due to the *'rates of particle diffusion, agglomeration, resuspension and deposition*' (HSE, 2004: WP). This can have an adverse affect due to the nanoparticles then being spread over a larger area causing greater levels of worker exposure. According to HSE (2004) workers are more at risk from

aerosols that contain a smaller particle size that can be inhaled. HSE claim that at the micrometre scale, behaviour of nanoparticles in aerosols is governed by, *'inertial, gravitational and diffusional forces'* (HSE, 2004: WP). As particle size decreases to the nanoscale, diffusional forces become dominant allowing behaviour that is similar to gas or vapour, and thus, increasing the spread. HSE therefore believes that it is necessary to examine the differences between large *'inertial'* and small *'diffusional'* particles in relation to aspects of exposure and control (HSE, 2004). This further increases the potential measurement requirements in a workplace, and raises questions about the practicability of such an approach.

Although a discussion of nanoparticle liberation into the air has been discussed, nanoparticles may also enter the workplace from leaks (thus in a liquid form). In such cases, nanoparticle accumulations on surfaces are more likely to enter the body through the skin. Surface based nanoparticle contamination raises further problems as the collection methods for examining nanoparticles are different to air-based contamination, and swabbing may miss or highlight un-representative areas of contamination (HSE, 2004). Decontamination of nanoparticles is problematic as normal cleaning processes are not always effective, creating a possibility that workers could suffer chronic exposure from dermal and ingestion routes if the nanoparticles remain in a contaminated workplace for any length of time.

Although numerous difficulties have been highlighted in this section, moves are being made towards addressing some concerns, although arguably at a limited rate. For example, ETUC are encouraging Member States to set up a register of workers' exposure to nanomaterials in association with health surveillance programmes. As a starting point, valuable information for future studies can be collected and examined for the prevention of occupational diseases, such as chronic effects of engineered nanoparticles in the human body, which might only become noticeable in the longer term (ETUC, 2011).

Drawing on concepts raised in this section, the next section focuses on the dangers of working with nanoparticles.

6.3.1. Dangers of Working with Nanoparticles

Workers may be exposed to nanoparticles in the workplace at various times, in different environments, and either inhaled, ingested or absorbed through the skin, which may also occur for customers, but through potentially different mechanisms. Considering the numerous workplace activities that are carried out in any sector using nanoparticles, the events causing unintended or undesired nanoparticle release into the workplace are numerous, and can for example include procedures such as cutting and grinding, as well as cleaning etc. (NIOSH, 2009). To more fully understand the phenomenon of workplace nanoparticle toxicity and risk, it is arguably necessary to identify the hazards from different nanoparticles, with current strategies to do this being at an early stage. Importantly, current information points to bulk scale products having different properties to their counterparts at the nanoscale, which creates unique challenges for addressing nanoparticles in the workplace. This is being compounded by conventional sampling and detection methods for carrying out occupational safety monitoring not being adequate for nanoparticles. Current occupational exposure limit values (OELVs) may not be relevant for nanoparticles, according to the Chemical Agents Code of Practice (HSA, 2010). All of these aspects are against a backdrop of a relative paucity of data to show the toxicity of nanoparticles in different workplaces (NIOSH, 2009). This has in turn resulted in the Health and Safety Authority (HSA, 2010) recommending a 'Precautionary Approach' using control measures to include engineering controls that involve a total enclosure of a process and containment control, so that any dust will go through a ventilation extraction allowing only purified air to be recirculated (HSA, 2010). Providing that the nanoparticles are in the air, and can be cycled through a fit-for-purpose ventilation system, this may go someway to resolving part of the risk of nanoparticles, but raises a further question about the maintenance of a ventilation system 'full' of nanoparticles.

Importantly, the HSA has stated that at present there have been no specific health effects that have been explicitly associated with nanoparticle exposure in the workplace. This is due to the lack of any scientific and medical evidence, which is arguably from a current lack of adequate methods to measure exposure to

nanoparticles. This appears a somewhat circular argument by the HSA, where an inability to measure something has resulted in a lack of evidence, thus making it safe. Based on this 'finding' the HSA has not recommended occupational health screening (HSA, 2010). Looking beyond workplace detection and screening, which as already argued is challenging, there is laboratory evidence albeit not from the workplace, that nanoparticles can be toxic, as shown in Table 6.1.

Method of Risk	Risk
Inhalation	Evidence exists that certain nanoparticles may be deposited in the respiratory tract if inhaled. This can cause inflammation and potentially damage cells (NIOSH, 2013).
Skin absorption and inhalation	Titanium dioxide commonly used in sunscreen and other commercial applications including paint, paper, cosmetics and food, can be produced in a varying size of particles including nanoparticles. NIOSH has determined that nanoscale titanium dioxide particles have a higher mass – based potency than larger particles. This suggests that occupational exposure to nanoscale titanium dioxide by inhalation could be a potential occupational carcinogen (NIOSH, 2013).
Skin absorption	There is a possibility that certain nanoparticles have the ability to penetrate cell membranes causing damage to intra cellular structures and cellular functions (NIOSH, 2009).
Environmental	Nanoparticle dusts may be combustible and could ignite easier than larger dust particles creating a risk of explosions and fires. Examples of this are wood and sugar (NIOSH, 2009).

Table 6.1. Nanoparticle risks to humans and the environment.

Within the workplace, there are only a few current occupational exposure limits specifically set for nanoparticles. This is an area that should be addressed due to certain nanoparticles having the potential to be more hazardous than their counterparts in the bulk state (NIOSH, 2009). Thus any existing occupational exposure limits for a substance may not give adequate protection for substances at the nanoscale, and is in need of reform. This is not to suggest that no moves have been made to set occupational limits, but more that they are the exception rather than the rule. An example of an existing limit recommended by the OSHA,

is for worker exposure to nanoscale titanium dioxide, which should not exceed NIOSH's 0.3 milligrams per cubic metre. This is in contrast to fine scale particles of titanium dioxide (particle size of greater than 100 nm) is 2.4 mg/m^3 (NIOSH, 2009). Exposure limits for other nanoparticles have not been set yet, therefore NIOSH recommend that safety measures should be put in place by minimising exposure using hazard control and best practice measures. These include, (1) assessing worker exposure to nanoparticles to control and identify all measures needed to determine if controls in place are effective, (2) tasks where workers could be exposed to nanoparticles should be detailed, identified and described, (3) identifying the state of the nanoparticle *i.e.* dust, powder, droplets or spray, (4) identifying exposure routes *i.e.* inhalation, ingestion or physical contact, and (5) determining an appropriate sampling method to measure quantities of exposure such as airborne concentrations and duration of exposure. As NIOSH (2009) explicated, it is important that companies determine what additional controls are needed to limit workers' exposure and adopt the most affective strategies. Importantly, NIOSH are proposing an inventory of tasks that will include information on the duration and frequency of anything that could result in exposure as well as the quantity of material being handled, the physical form of the nanoparticle and its dustiness. This exposure assessment has the ability to help with the understanding of exposure potential and could provide guidance for controls for exposure mitigation (NIOSH, 2012).

A set of strategies for decreasing and potentially eliminating worker exposure are required as a way of exposure control. For example, workers can limit their exposure by job rotation and good housekeeping procedures such as spill prevention, correct labelling and proper storage. Exposure sources during the life cycle of the nanoparticle need to be evaluated with its disposal at the end of life stage following regulations as for contaminated refuse. It is interesting to note that many products containing nanoparticles may change their exposure potential during their life cycle. An example of this is liquid paint when applied changes to a solid form once dried. The dried surface suffers abrasion and weathering that could lead to further exposure (Hansen, 2009). This should raise the level of concern due to the challenges of measuring nanoparticles in the work and home place.

As Howard (2012) posed, what are the properties that may influence or determine the inherent hazards of nanoparticles? Questions are also being raised about the appropriateness of current H&S legislation, guidelines, test protocols and animal models that are being used to assess risks to humans due to doubts of suitability of the models being used to identify low dose and long-term effects (Howard, 2012; Kearns, 2012; Loft, 2012).

A management tool used for protecting workers from potentially hazardous working conditions is Prevention through Design (PtD). This tool allows occupational health and safety issues to be addressed by eliminating hazards and minimising risks during the whole life cycle process. PtD is also used as a cost effective method in many nanotechnology research laboratories to enhance occupational health and safety within their facilities (Murashov and Howard, 2009).

A pertinent question that needs to be raised when dealing with nanoparticles in the workplace is; can the protection equipment that is currently available today be effective enough to protect workers from the potential hazards including inhalation, dermal contact and ingestion? An examination will be made of this aspect, with the next section exploring inhalation of nanoparticles.

6.3.2.1. Inhalation

One of the commonest ways a worker may be exposed to engineered nanoparticles is through inhalation via the mouth or nose (Hoet *et al*, 2004). The greatest risk of exposure of inhalation is from nanoparticles in a dry powder form. Liquids containing nanoparticles present less of a risk, while the least risk being from nanoparticles that are incorporated into a solid, due to their limited mobility (NIOSH, 2009). Dusty materials present a particularly large problem due to their propensity to liberate nanoparticles into the environment. During the manufacturing process, synthesis and material handing can potentially increase exposure to an employee. Other ways of increased exposure can be through open manual handling of bulk amounts of nanoparticles, high energy processes

including sonication, grinding, blending and milling, all of which can potentially cause the release of nanoparticles (Gohler *et al,* 2010; Johnson *et al,* 2010).

The European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC, 2006) believes the inhalation of nanoparticles to be one of the main areas of concern, due to potential negative effects of nanoparticles that may occur in the human body. The first site of major concern in the human body is the respiratory tract, which aims to filter unwanted materials but may itself be damaged by the presence of nanoparticles (Hoet *et al*, 2004). Smaller nanoparticles have a greater potential to penetrate the lining of the lung, due to their relatively small size (ECETOC, 2006). Different nanoparticle sizes can thus damage the respiratory system at different levels. Beyond direct physical damage, nanoparticles can reduce the ability of the respiratory system to function correctly, and in particular inhibit its ability to clean itself, which can facilitate the creation of disease states. Hoet (2004) has argued that this problem is independent of the toxicity of the material at the nanoscale but is more related to size and shape of the nanoparticles. Work carried out by Wilson *et al* (2002) and Donaldson *et al* (2003) have shown that inhaled nanoparticles can result in airway inflammation, triggering of asthma, blood clotting, and cellular death. Beyond direct damage to the respiratory system, ECETOC (2006) has reported that where insoluble or slowly dissolving nanoparticles are deposited on the walls of the respiratory tract, they are only partially moved by mucus or coughing and are instead swallowed, which can create problems in the digestive systems, where damage can be done to the intestines, liver and kidneys (Behrens *et al*, 2002; HSE, 2004). Perhaps more worrying are the animal studies carried out in medical research, that have shown that nanoparticles can change their chemical composition, crystal structure and particle size, all of which can alter their toxicity. This creates a great potential difficulty of assessing nanoparticle toxicity, if the interaction with a living host changes nanoparticle size, shape, crystal structure and toxicity upon entering a host body (NIOSH, 2009).

The new ISO 10808 standard (2010) contains new guidelines in a bid to help industry assess the possible risks in the growth of nanoscale - based products by increasing safety for workers and consumers. ISO has attempted to take into

account particular characteristics and potential risks of nanoparticles thus it may be an important step towards regulation (ETUC, 2011).

For workers handling nanoparticles and being exposed to them on a regular basis, it is important for their health and safety that regulations for the control of airborne particle pollution are set in place. Uncertainties and research gaps have a propensity to create difficulties for management decision-making about health risks (NIOSH, 2009). More research is needed so that exposure limits can be set, preventing dangerous doses from being reached during the lifetime of those exposed. As of yet, no data is available to determine a critical dose of nanoparticles that initiates disease states in humans (Bosso, 2010). This can be coupled with a lack of data in this area for humans in general (ICON, 2006). Methods to monitor worker exposure are hindered by a lack of universal sampling equipment that can be used to measure exposure (NIOSH, 2006; Maynard and Aitken, 2007). Many methods of measurement are simply not fit-for-purpose and cannot differentiate between different nanoparticles and whether they are toxic or safe (NIOSH, 2006; Fujitani *et al,* 2008). If measurement of nanoparticles in the workplace is currently unachievable due to lack of knowledge and technology, it may present an insurmountable challenge for constructing fit-for-purpose legislation (Hansen, 2009), or at least regulation based on sound scientific evidence. This is no small challenge, and arguably there is little suggestion for how to advance this area, and seems to suggest that while a rapid state of commercial exploitation of nanotechnology products has been sought, the predominant focus has been on manufacturing rather than technological innovation to assess product safety.

Moving on from inhalation, the next section examines the ingestion of nanoparticles.

6.3.2.2. Ingestion

Ingestion of nanoparticles involves an individual directly or indirectly eating or drinking nanoparticles, or food and liquid contaminated with nanoparticles.

Practically, this is far less likely to happen in comparison to inhalation, as the opportunities for ingestion are arguably lesser (NIOSH, 2009). Importantly, and according to HSE (2004) guidelines on the health and safety of nanoparticles, relatively little work has been carried out to understand nanoparticle ingestion. Studies have so far been limited to food contamination from hand to mouth including sources such as lead nanoparticles from paint. Although from a non-nanoparticle study, Sen *et al* (2002) showed that scaffolders working with pipes containing lead had high levels of lead poisoning from penetration of lead through the skin, and eating practices. This suggests that the risk of contamination from potentially toxic materials must be considered with more nuanced thinking to more fully capture the risk.

If using the lens of risk, there is a potential to misconstruct the ingestion of nanoparticles to that of accidental ingestion, which potentially misses out intentional ingestion, as would be the case of nanoparticle pharmaceutical products. These products, take advantage of the small size of nanoparticles to enhance product activity and to more accurately target desired parts of the body, such as a tumour. However and irrespective of the intentionality of ingested nanoparticles, there is still risk with their ingestion (including pharmaceutical nanoparticles). A document presented to the House of Lords in 2009 (publications.parliament.uk, May 2009: WP) examined evidence into known risk factors associated with the exposure of nanoparticles. It claimed that current research has indicated that nanoparticles are able to penetrate cell membranes in the lining of the stomach wall, potentially passing through the epithelium into the lymphatic vessels or the bloodstream. Chaudhry (2009: 113) argued that there is excellent mobility both inside and outside of the cells potentially accessing *'all areas of the body, even the brain and all areas of the cell including the nucleus'*. If this is the case, and bearing in mind this is a wide-ranging claim, it would suggest caution in the use of nanoparticles that may be ingested. Stepping back to look at the physicality of nanoparticles within a human body (although the argument could be extended to other animals), do nanoparticles remain as nanoparticles once digested? It is certainly possible that nanoparticles may undergo processes that result in their breaking into smaller parts or aggregating

into larger scale particles, which may influence their toxicity. Chaudhry (2010: 36) argued that:

> *'If nanomaterials are solubilised, digested or degraded within the gut then they are of least concern…The main concern is of insoluble, indigestible, non – degradable nanoparticles that can survive mechanisms in the gut'.*

While informative and insightful regarding the dangers of insoluble nanoparticles, which may interact with the body beyond digestion in a negative way, it is perhaps limited in its scope. For example, the dissolution of lead nanoparticles, into smaller parts would not necessarily make the material 'safe'. It has however been argued that insoluble nanoparticles present the most risk, which was stated by SCENIHR (2009: WP):

> *'Toxicologists agree that the persistent nanoparticles, especially those that are non – biologically degradable, inorganic, the inorganic metal oxides and metals, are the particles that pose the most risk'.*

Importantly, the potential health impact on humans and other animals from nanoparticles is still predominantly unknown. With an increasing use of nanoparticles in a greater number of products that interact with food and liquids, including for instance fridge-freezers (Donaldson, 2008), this is not a small problem and I believe is an area worthy of much greater study, to elucidate the risks and to work towards more fit-for-purpose regulation.

Building on this and the prior section, which have examined nanoparticle ingestion and inhalation respectively, the next section considers dermal exposure.

6.3.2.3. Dermal Exposure

Dermal exposure to nanoparticles typically refers to physical contact of nanoparticles with the skin and hair follicles (Tinkle *et al*, 2003), where the nanoparticles may remain or further penetrate into the body. Evidence based risk is currently lacking in this area, and HSE (2000) have claimed that there is no evidence to suggest that there is any specific health problems associated with dermal penetration by nanoparticles. Arguably, it might be more fitting to reframe this as there is insufficient evidence based on a lack of studies, rather than no evidence from a lack of risk, which potentially suggests examination, which failed to show risk. Unfortunately, little work has been carried out in this area, meaning that much discourse is speculative.

Schneider *et al* (2000) highlighted perhaps the greatest problem for assessing nanoparticle related dermal toxicity, is the technical challenge of monitoring. Currently, although this is likely to change, the equipment to measure nanoparticle dermal toxicity is limited, resulting in many claims being made about bulk scale rather than nanoscale materials. Further to this, is the use of animal models rather than skin on a human, with the former being informative for the latter, and raising the question of validity to humans? Importantly, where animal models have been used, dermal exposure to nanoparticles has a potential to cause harmful effects locally either on the skin, within the skin or if the substance is absorbed, by dissemination throughout the bloodstream causing systemic effects. These effects are more pronounced in areas of high exposure, more susceptible areas of the body such as the inner thighs, and with an increased length of exposure (Schneider *et al*, 2000). Although attempts have been made to more fully understand this area, the scientific link between claims being made and risk management is thus largely unknown, which hampers not only management but also the potential for fit-for-purpose nanoparticle regulation.

As with ingestion of nanoparticles, pharmaceutical companies have shown an increasing interest in the potential to exploit the ability of nanoparticles to penetrate the dermal layer as a delivery system for their products. Particular areas

of interest to the pharmaceutical industry include drug delivery and anti-aging cosmetics. Friends of the Earth (2006), has raised concerns about the use of such products, which are currently being sold globally, which in fish models have shown the potential of such products to penetrate the brain and cause gene and brain damage. Oberdőrster (2004: WP) showcased the problem by stating:

> *'Given the rapid onset of brain damage, it is important to further test and assess the risks and benefits of this new technology before use becomes even more widespread'.*

This raises the question as to whether nanoparticles used dermally are able to penetrate the human skin layer and travel through the bloodstream to major organs, and if so, what damage can they do? When considering the increasing use of nanoparticles in products, (for example sunscreens that contain nanoparticles of titanium dioxide and/or zinc oxide), this is potentially not a small problem (IARC, 2006; The Friends of the Earth report, 2006; Benninghoff and Hessler, 2008). Again the issue arises for how to address a lack of technology to suitably address these concerns, whereby at present it is potentially hugely problematic to detect and elucidate damage being done to the body by these products. This is not simply an issue relating to a lack of technology to do this but also a lack of skilled operators as well as recognised and potentially 'validated' methodologies to achieve this goal.

Although this particular section has arguably raised more questions than it has answered, and examined the direct risks of exposing the human body to nanoparticles, the next section explores environmental issues of nanoparticle release and contamination.

6.4. Environmental Issues

While the last section 'Nanoparticles in the Work and Home Place' examined intentionally and unintentionally released nanoparticles in two specific environments, nanoparticles can be released in many other environments, which

may fill the demand for various societal drivers, but may also produce long-term negative societal and health impacts, particularly in the wider environment. This section therefore focuses on nanotechnology, with attention being paid towards nanoparticles in what has been termed 'the green revolution' (Bosso, 2010).

As a general backdrop to this section, it is worth emphasising that non-human produced 'natural' nanoparticles have existed in the environment for millions of years, if not longer. Simply, natural nanoparticles can be found in ocean spray, volcanic ash, clouds, forest fire smoke and clays etc. (Hutchison and Malone, 2011). These nanoparticles are usually believed to be harmless to the environment unless an environmental incident occurs i.e. a volcanic eruption, where an excess of nano and other scale particles can result in the damage to human, animal and wider environmental health. This could however be just a simple discursive framing, as little academic attention has been paid towards naturally occurring nanoparticles and their health and safety impact, in comparison to their human made nanoparticle counterparts.

Looking at the intended use of nanoparticles within the environment, examples can be found for global projects, such as providing clean water for the 1.1 billion people without access to clean water (Prentice and Reinders, 2007). Non-nanoparticle products, while somewhat effective for cleaning water are often cost prohibitive i.e. too expensive and can create environmental damage (Bernhardt *et al,* 2010), whereas nanoparticle products offer a potentially cheaper and more scalable solution. While nanoparticle products may offer a lot commercially and for cleaning water at a relatively low cost, the long-term effect is simply not known. Coupled with this has been a lack of research into longer-term effects to understand the ecological effects of such products (Bhattacharya, 2012). Titanium dioxide nanoparticles, which are currently being used in this area, have been shown and as already argued within this study, to create potential toxic effects (Bhattacharya, 2012).

The promises of nanotechnology for environmental scientists have become a double edged sword. There are positive and negative aspects that need investigating, as there has been little research into the key areas. There are those

who believe that nanotechnology holds the key to the future by being the saviour of the planet due to novel pollution prevention methods and remediation approaches, with it even being called 'the next green revolution' (Bosso, 2010). With this in mind it is important to examine the evidence presented by HSE posed to human health and the environment that unfortunately has often been contradictory. Some policy makers and environmental scientists conclude that the risk posed is incredibly small whereas others such as Oberdörster (2004) believe that the risk is great to both human health and the wider environment. Currently the safety and danger of nanoparticles is very difficult to evaluate due to a lack of knowledge of their fate and toxicology posing the question of how to regulate. Concern has been expressed about the risk of silver nanoparticles destroying microbial communities, due to silver being an antimicrobial. According to Oberdörster, (2004) they have also been found inside the brains of large mouthed sea bass.

There is a growing dilemma posed by nanoparticles to understand the potential risks that they can cause to human health and the environment. Different individuals and organisations interpret the same information in very different ways often taking into account their own interests that may colour their judgement. There are three different approaches when examining governance of these novel materials.

The first approach is one of optimism. It claims that no regulatory attention should be necessary unless there is proof or at least a clear indication that harm has been or could be caused. This approach is seen to prevent the suppression of innovation as regulation is often claimed to stifle it. The second approach is a less optimistic one, and argues that any attempt to regulate nanoparticles should be 'risk based', so that legislation would only be enforced when there is scientific proof that there is the probability of danger. This approach 'assumes' that science is able to detect risks at an early enough stage to prevent damage. Currently much science is contradictory when examining nanotechnology. The third approach is the view that nanoparticles should not be used in products until they have been proven to be safe not only to human health but in the environment. This creates the problem that consumers may be denied health

benefits and technologies that have the potential to generate a positive lifestyle effect.

There have been many instances in history where substances have been used without rigorous 'real world' testing. These include thalidomide, GMO and asbestos (Carman, 2008). Therefore it is important to avoid assumptions that have the potential to create serious consequences. Currently it is not feasible to answer questions on the impacts of nanotechnologies without using traditional regulatory frameworks that are risk based. Collingridge (1980: 16) described this problem as the '*technology control dilemma*' further stating:

> *'in the early stages of a technology we do not know enough to establish the most appropriate controls for managing it. But by the time problems emerge, the technology is too entrenched to be changed without major disruptions'*.

This suggests nanoparticles, like other emerging technologies *'require an adaptive governance regime capable of monitoring technologies and materials as they are developed and incorporated into processes and products'* (Collingridge, 1980: 32). Adaptive management systems more capable of responding to new information are needed to look beyond the traditional regulation solutions. This is a substantial challenge that moves towards the governance of innovation and away from the governance of risk, striving towards an adaptive and open system to encourage innovation but capable of preventing harm to human health or the environment (Jasanoff, 2005). Moving on from these areas, the following section considers nanowaste and nanopollution.

6.4.1. Nanowaste and Nanopollution

While attempts have been made to catalogue nanomaterials regarded as waste or pollutants, the 'Databank of Nanomaterials' at Nanowerk lists 25 nanomaterials, which is a very low number when considering the number of commercialised nanotechnology products (nanowerk, 2015: WP). This is not a complete list, and

for the nanomaterials listed, there is very little known about the behaviour of nanomaterials when they enter waste streams or their various end of life cycles. More information is needed to give a better understanding of the risks at the end of their product life. This would suggest that better disposal pathways plus potential transformation processes for nanomaterials are needed for nanomaterials in waste treatment plants (nanowerk, 2015: WP). This is due to little consideration having been shown for what are often unique properties of nanomaterials in the recovery or recycling stage.

At present, there is no legal framework for separate treatment of waste containing nanomaterials. As there are no monitoring procedures, a prerequisite obtaining the exact knowledge about the nanomaterials being used such as the type, composition, potential transformation, amounts and concentration is needed. This information is currently unavailable due to the lack of studies on the end of a product life phase of nanomaterial products. One reason for this is that there is very little known about nanomaterial wastes and their behaviour in biological, thermal or mechanical waste treatment plants or landfills.

Nanomaterials can be released into the environment at any stage during the life cycle of a product due to chemical or mechanical effects (nanowerk, 2015: WP). Boldrin *et al* (2014) argued that nanomaterials entering the environment diffuse into different sources and should be classed as *'nanopollutants'*. Nanowaste can be defined as applicable when nanomaterials come into contact with solid wastes and collected separately. Nanoparticles only become waste after their elimination from wastewater treatment plants after the biological purification phase. Therefore sludge containing nanomaterials requiring further treatment can be classed as nanowaste. Wastes containing nanomaterials that are from production processes and households are also classed as nanowastes. Figure 6.1, shows the difference between nanopollutants and nanowastes.

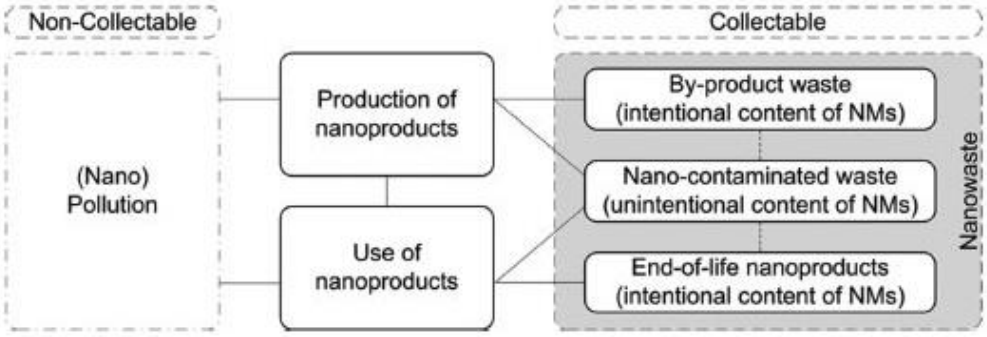

Figure 6.1. Differentiation between 'nanopollutant' and 'nanowaste' i.e. solid waste that contains nanomaterials (Bodrin et al, 2014).

It can be asked, why is the differentiation between nanowaste and nanopollutants important? The reason behind the necessary distinction is due to the Waste Management Laws (UK) (1996), the Hazardous Waste Laws (EU) (2009) and the Duty of Care Regulations transposed into the Waste (England and Wales) Regulations (2011) (gov.uk/waste-legislation, 2015). Nanowaste is therefore subject to these regulations although there is still no legislation specific to nanomaterials or mention of the term nanowaste.

At the present there is too little known about the behaviour of nanomaterials in waste incineration plants posing several questions about the disposal of large amounts from industrial facilities and viable alternatives such as chemo–physical treatment methods. There are issues surrounding collection due to the diverse amount of products containing them. Recycled products that contain nanomaterials often release nanoparticles during the recycling process. Swiss studies have shown that on average 0.00079 percent by weight of filter dust in the incineration plant present in the form as nanomaterials, making up less than 10 percent of the total amount (nanowerk, 2015: WP). This theme of uncertainty is considered in greater depth in the following section.

6.5. Uncertainties of Environmental Exposure to Nanoparticles

With an increasing number of commercially available products containing or based on nanoparticle technology, there is a growing need to understand the consequence of environmental risk from these products. There are several routes to nanoparticles being released into the wider environment, including (1) manufacturing processes, (2) transportation, (3) product usage and disposal, and (4) product degradation amongst others (Biswas and Wu, 2005; RS and RAE, 2004; Boxall *et al,* 2008). According to Christian *et al* (2008: 326-343) the environment may be impacted by nanoparticles in four different ways as shown in Table 6.2.

Effect	Consequence
Toxicity	Damages or kills natural biota.
Trojan horse effect	Negatively impacts the ability of natural biota to uptake and utilise nutrients.
Oxidation of natural organ material (NOM)	Indirect effect on an ecosystem that changes it negatively in some way.
Changing environmental microstructures	Addition of nanoparticles changes the physical structure of microenvironments.

Table 6.2. Negative Aspects of Nanoparticles in the Environment.

Currently there are no official figures for the total load of nanoparticles in the environment due to a lack of available monitoring equipment, fit-for-purpose analytical methods, and an incentive to detect and quantify nanoparticles (Muller and Nowack, 2008). According to Nowack and Bucheli, (2007: 5) part of the physical challenge of measurement is based on *'the lack of analytical methods to quantify nanomaterial effects in environmental matrices due to the complexity of both environmental conditions and nanomaterial physico – chemical properties'*. This is coupled with different levels of nanoparticles being released from products at different times in a product's life cycle. An example of this is paint, where nanoparticles are initially in a liquid form during application but as the paint dries they are encapsulated in a solid form once the paint has been applied. In this example, initial consumer exposure comes from the liquid paint but then

changes as the paint dries, becomes weathered and if physical abrasion of the surface takes place thus allowing nanoparticles to re-enter the wider environment. With such uncertainty, concerns must be raised about the lack of information from potential hazards not only to the environment but also to the consumer (Hansen, 2008).

There is a potential that manufactured nanoparticles can interact with ecosystems due to their small size and increased mobility, in comparison to bulk scale materials. Penetration into waste streams, water, soil, microorganisms, aquatic and land-based life could disrupt numerous ecosystems (AZoNanotechnology, 2008). It is important to recognise that risk assessments made for the release of nanoparticles into the ecosystem is done with great uncertainty. This uncertainty is magnified by the challenge of it potentially taking years to scientifically demonstrate nanoparticle toxicity in such environments (O'Donnell and Isaacs, 2010). Life cycle notions and end of life of these materials are all under question as it is unknown what makes a nanoparticle relinquish its reactive properties or how or what could reactivate them (Zhu *et al,* 2007). It would appear that there is a very real issue for humans and the environment being exposed to an unknown risk without strategies being developed to mitigate this uncertainty and risk. The current research zeitgeist is orientated towards finding lethal effects from nanoparticles, which has been at the expense of building an understanding of sub-lethal exposure and ecosystem damage, which could also bring other perturbations such as climate change or species invasion (Lyon *et al,* 2007).

It is necessary for governments to be aware of how and in what quantities manufactured nanoparticles from nanoscale products could potentially be released into the environment (EMPA, 2010). This poses the question as to what level of contamination can be expected in river or soil samples. It will be necessary for analytical methods that are suitable for investigating environmental samples of nanoparticle concentrations be established. This may be problematic due to some of the samples being at an undetectable level and therefore almost untraceable, leading to concern over the lack of standard or reliable equipment or methods to measure nanoparticles in the environment, including investigation into their potential risk (EMPA, 2010). It has prompted the Department for

Environment Food and Rural Affairs (Defra) alongside other global governments including many state governments in the United States, to set up special departments or 'task forces' to deal with these issues, such as nanoecotoxicology, which the following section examines.

6.5.1. Nanoecotoxicology

Numerous studies have clearly highlighted the potential commercial advantages and opportunities of utilising nanoparticle technology in products. This must however be tempered against nanoecotoxicology, which is the damaging and lethal effect nanoparticles may have on the environment and ecosystems. One of the most challenging aspects of nanoparticles argued by Hansen (2009) and Migliore *et al* (2009) is that over time, nanoparticle properties have the potential to change. This can include oxidisation, changing surface coatings, and overall size and shape of the nanoparticles. Importantly, nanoparticle 'aging' under natural environmental conditions has been limited to examining the phenomenon in laboratory conditions, at the expense of a plethora of environmental conditions in the 'real' world. To circumvent this myopic view, there must be a greater examination of nanoparticles during the aging process under natural environmental conditions, taking into account these effects, which can be used to better inform regulatory systems.

With much positive exposure of the perceived benefits of nanoparticle technology, entities such as The World Bank (the United Nations Food and Agricultural Organisation) UNFAO are looking at using nanoparticle applications to feed a growing world population where natural food production is under strain (Suppan, 2013). These agricultural applications particularly for crops have the potential to decrease the volume of pesticides by using silver nanoparticles and nanoscale metallic oxides that would target soil pathogens (but may also kill beneficial microorganisms). This is arguably a reductionist view of targeting one problem, while ignoring the wider implications and detriments of such technology.

In 2006, Oberdörster *et al* (WP) published a document in the Environmental Law Review advising: *'it would be prudent to examine and address environmental and human health concerns before the wide-spread adoption of nanotechnology.'* So far, only some medical arenas of nanotechnology have heeded this advice. Thus, many governments have allowed thousands of consumer products to be marketed that have nanoparticles incorporated into them to be commercialised before any pre-market safety assessment has taken place.

European Commission Directorate General for the Environment, (February 2010: WP) claimed:

> *'To date, no legislation or regulation exists that is specifically targeted at soil biodiversity, whether at international, EU, national or regional level. This reflects the lack of awareness for soil biodiversity and its value, as well as the complexity of the subject. Several areas of policy directly affect and could address soil biodiversity, including soil, water, climate, agricultural and nature policies.'*

Consumer products containing nanoparticles continue to be developed and commercialised without governmental regulation (Rizzuto, 2009: WP). *'As agri-nanotechnology rapidly enters the market, can soil health and everything that depends on it be sustained without regulation?'* asks Suppan (2013: WP) *'That's the question regulators, researchers and anyone involved in our food system should be asking themselves.'*

Without a regulatory system in place for the production or sale of fertilizers containing nanoparticles, soil scientists, farmers, biological engineers and public health professionals need to request governments to make robust assessments before allowing such products to be indiscriminately used by industry. To showcase this problem in greater depth the following section considers nanosilver and its use in the environment.

6.5.1.1. Nanosilver

Nanosilver is a collection of products based solely on or using nanoscale silver, usually in a nanoparticle form. It has become a popular product for killing undesired microorganisms such as bacteria, as it has inherent antibacterial properties. Examples of product usage include swimming pools, washing machines, socks, deodorant, Elastoplast and toothpaste. Luoma (2008) estimated that between 10 - 30 percent of USA households use silver as a biocide, potentially in a nanoscale form. This has the potential to create a mass release of silver nanoparticles into the environment. The estimate by Luoma is based on the release of silver nanoparticles from three products; swimming pools, washing machines and socks. Looking more in depth at this issue, the contribution from socks containing silver nanoparticles depends on the amount of silver contained inside the product. The lower end estimate was between 6 - 930 kg and the higher end estimate was between 180 – 2790 kg (Luoma, 2008). The estimate for the discharge from washing machines containing silver was 2850 kg with the contribution from swimming pools being approximately 30 tonnes. Luoma (2008) also estimated that in the future, 457 tonnes of silver could be discharged into wastewater. This figure has the potential to be reduced by waste treatment to approximately 128 tonnes if 80 percent of the discharge is treated and 90 percent of the silver is removed from these products or if an after stage silver removal treatment. There is little evidence to suggest there is any serious move to address either potential strategy for silver removal at this time.

It has been estimated that over 300 tonnes of nanoscale silver are used globally per annum (Kaegi *et al,* 2013), which is not necessarily surprising as silver is effective as an antibacterial agent against over 650 disease causing microorganisms (ETUC, 2011). Cost is also an important factor due to the increased surface area of nanoparticles where one cubic centimetre of nanosilver has the equivalent surface area of two football fields. Thus less silver is used when in a nanomaterial form. Although less silver has the potential to be less harmful to the environment, in a nanoscale form, lower levels can be more potent than their bulk forms, which can be more damaging to the environment.

Nel (2012) carried out research into the potential dangers of silver nanoparticles on aquatic life. They found that the geometries of these particles are the essential determinant in the toxicity of aquatic life (nanowerk, 2012: WP). The importance of this study and those similar is due to the concern over the amount of products currently on the market containing silver nanoparticles, with unknown geometries and associated toxicities. Nel (2012) found that the environmental toxicity from the silver nanoparticles was due to the defects on their surface capable of damaging cells. This is an important point, as prior to this research, it had been believed that the toxicity was from the release of silver ions. Therefore this study has revealed that silver nanoparticles have a potential to damage aquatic organisms prompting the need for safety questions to be asked about their impact not only on aquatic life but also on human cells.

Tracking the life cycle of nanoparticles in the environment has also received much attention. The Lake Ecosystem Nanosilver (LENS) project examined the disposal of nanoparticles and in particular nanoscale silver (nanowerk, 2012: WP). The pathway these particles travelled throughout the waterways into rivers and lakes showed similar results to that of Nel (2012) in that nanoscale silver has the potential to damage aquatic organisms and particularly algae, zooplankton and bacteria, which are at the bottom of the food chain.

The importance of the results from studies such as LENS is that they can be used to help policy makers decide whether and to what extent nanoparticles are toxic to aquatic life and ecosystems and whether regulatory action is required to protect and control their release into the environment. With the Nanowerk (2012: WP) estimate that 30 percent of nanoproducts contain silver nanoparticles, it is important that this area is elucidated. To date there is no evidence that nanoparticles have caused actual harm from their current applications to larger organisms such as humans, but due to the uncertainty of their behaviour in the environment and lack of adequate testing, adverse effects may still occur (Porter *et al,* 2012).

In the UK, a collaborative research group from DEFRA, the Natural Environment Research Council (NERC), the Engineering Physical Sciences

Research Council (EPSRC) and the Environment Agency was formed in 2006 to investigate the behaviour and life cycle of manufactured nanoparticles in the environment. This group is known as the UK Environmental Nanoscience Initiative (ENI). As nanotechnology is in many ways still in its infancy, the environmental unknown risks associated with manufactured nanoparticles remain high. The ENI (2010) has highlighted areas for concern being the need to understand sources, pathways, fate and persistence, outputs of nanoparticles, bioavailability and environmental exposure. There is a fundamental need to understand the behaviour of nanoparticles in the environment plus any potential interaction with other chemicals that have the potential to influence bioavailability.

Finally, and as hinted at throughout this chapter so far, health and safety risks can act as a commercial barrier for companies engaged in nanoparticle R&D and commercialisation. Thus, the following section explores health and safety risks as a commercial barrier.

6.6. Health and Safety Risks as a Commercial Barrier

With many varied perspectives and conflicting discourses on nanoparticles and nanotechnology, it is not surprising that such products are perceived as being risk-laden by numerous stakeholder groups. According to Davies (2010), there is a large majority of the population that has little knowledge of nanotechnology, but this does not mean that they do not have an opinion on the subject. Many people obtain these opinions from dissemination of information from different communication channels such as the mass media, which widely disseminates quite different views. These views, which can often misconstruct nanotechnology into positive and negative stories, should not be dismissed lightly. Perceived risk is a real barrier that can only be overcome with the production of information that allows the public to properly understand the technology. Arguably, this is the same for the development of regulatory systems based on fit-for-purpose scientific research rather than story telling.

There are many examples of prior commercial technologies that have suffered from the media. An example of negative publicity is genetically modified food, which has been more hype than product (Greenpeace, 2010). The challenge for interested stakeholders is to be able to engage with nanotechnology and cut through the pervasive misconstructions of the technology that shroud its capabilities and risk. Looking briefly at genetically modified foods, the growth of this technology was slowed down due to the high level of public fear that was perceived, particularly in Europe (Sandler and Kay, 2006). The fate of GM foods demonstrates the fickleness of the public who can quickly change their opinions on emerging technologies if they believe they can be detrimental to their health and safety or to the environment (Landy, 2010). This can have disastrous consequences for commercial entities engaged in R&D and commercialisation. Generally, and for high technology products, public concern has often prompted governments to take action by selecting investigating panels and regulatory institutions to determine new laws and policies to prevent environmental effects and protect human health (Bosso, 1987). The public has come to expect government to protect them at some level from risks that individuals cannot understand or control (Landy, 2010).

Risk assessment is a process that can assess impact of exposure, identify hazards and set regulations to correspond to findings. A constant feature of risk assessment is uncertainty. Ruckelshaus (1983: 1026) describes risk assessment as a *'shotgun wedding between science and the law.'* He claims that, *'science thrives on uncertainty'* but *'laws often assume, indeed demand, a certainty of protection greater than science can provide with the current state of knowledge'*. There is also a fundamental question associated with risk assessment of nanotechnology, which is; are theoretical and demonstrable assumptions about the bulk operable at the nanoscale? As stated by Tostoshev (2006: 21)

> *'The unique properties and extremely small size of nanomaterials are such that even determining the full extent of the risks to human health and environment is currently beyond the means of existing risk assessment frameworks… we don't know will not likely be an*

acceptable response should public concerns about the safety of nanomaterials be aroused.'

This poses the question as to whether all nanoparticles and nanoproducts carry an equal risk. The answer to this question is simply no. For example a sticky bandage containing silver nanoparticles placed over a small cut is likely to be less toxic and harmful than nanodiamonds being placed into an oral cavity where a root canal filling is being carried out. An argument can be made that governments need to be transparent, effective and responsive to the perceived risks of nanoparticles on behalf of the public so that trust is maintained. Any 'muddled' responses (Tarrow, 2000) as seen in the 1990s with the bovine spongiform encephalopathy (BSE) or 'mad cow' disease, can persuade the public to mistrust policy makers and their claims that new technologies may pose little risk. The promises of nanotechnology should not be constrained or rejected due to public anxiety from potential risk. Therefore it may be necessary for the public to trade off any potential risks in order to receive any potential benefits (Bosso and Kay, 2010). Commercial entities are not exempt from the discourse and physical activity in this area, as it directly feeds into their R&D, funding streams and ability to commercialise their products.

Risk assessment of nanoparticles need to be performed on a case-by-case basis, due to their unique properties (Kobe, 2012). Counter commercial arguments can be made that such a task might be cost prohibitive, demanding and impractical. Chaudhry (2012: WP) has suggested that there might be as many as:

'50,000 potential combinations of single walled carbon nanotubes (SWCNTs), depending on structural types, length, manufacturing and purification processes, and surface coatings. Each one of these SWCNTs has different chemical, physical and biological properties that may determine their overall hazard.'

From a scientific perspective, testing is no small task and may well create additional costs for R&D as well as for companies with products already being

sold into the marketplace. However, specific case-by-case reporting of nanoparticle properties and their implication for environmental and toxicological behaviour is at some level necessary if a deeper understanding is required to facilitate description, recognition and evaluation of applications of families of nanomaterials (Chaudhry, 2012). It has been suggested that with so many gaps in scientific data, ambiguity and uncertainty, traditional risk analysis may lead to a *'paralysis of analysis'* (EEA, 2001, 2013). This can be caused if too much time is spent waiting for the completion and results of the risk assessments with a loss of focus on the implementing of measures that have the potential to reduce or prevent possible risks. A framework of communication is needed from manufacture to end of lifecycle of nanoscale products (Grobe, 2012). The International Risk Governance Council (IRGC) noted in 2006 (14) that a:

> *'... lack of communication and understanding about the science, application and regulation of nanotechnology among all stakeholders may have negative effects on societal impressions and political / regulatory decision making.'*

Thus more informed communication could be considered a vital part of the commercial journey of products to market, and their longer-term acceptance and adoption (Rogers, 2003). Communication allows stakeholders to make better-informed choices about risk and facilitate commercial activities (IRGC, 2006). Regulation can be an important part of elucidating information regarding product safety, but as previously mentioned, can also add additional costs, which manufacturers do not wish to pay.

Finally, and after much discussion in this chapter, the following section makes a summary of the themes so far considered.

6.7. Summary

This chapter has provided an in depth examination of health, safety and the environmental issues as they pertain to nanotechnology and nanoparticles.

Building on an understanding of what the HSE often aims to achieve, the difficulties for using this framework to engage with nanoparticle products has been highlighted. More specifically, it was noted how a lack of scientific data and monitoring of products from the R&D stage and in commercial use has reduced the potential to use scientifically based knowledge to better inform health and safety regulation. This is particularly worrying considering the high number of products commercialised and number of workers being exposed as well as users to these products. With potential risks being present from product inception through to and including the disposal stage, the lack of engagement by bodies such as HSE may not best suit the users and workers engaging with these products. More than this, there is at present little focus being paid towards developing technologies and methods to assess this area, meaning it is unlikely that anything will change any time soon. Thus we are left with a system focussed towards rapid commercialisation, with limited attention being paid towards unpicking and highlighting aspects relevant to health, safety and the environment.

While this chapter focussed on workplace health and safety aspects related to nanoparticles, it is also possible to view much of this discourse as being relevant to end users, who may also be exposed. Drawing on the more frequently discussed arena of the workplace, it should also be noted that there are arguably also a great number of health and safety risks from using nanoparticle products, which at present is not receiving enough attention. Discussions for how to regulate this aspect are thus limited.

The following chapter goes on to consider the regulatory landscape that risk mitigation exists within for nanotechnology and nanoparticles.

Chapter 7. Regulatory Approaches to Nanotechnology

7.1. Introduction

This chapter is driven by the research question, 'what are the regulatory approaches to nanotechnology and nanoparticles that might best result in regulation promoting innovative commercialisation while addressing needs to mitigate risk?' This chapter sets out to examine the regulatory approaches to nanotechnology which are situated between a driver to mitigate risk, while promoting commercial activities, which benefit numerous economies and societies through revenue, employment and utility from products. It is accepted that any approach to regulation is in essence a balancing act where different stakeholder drivers must be weighed up, and consideration is made about what regulation is striving to achieve and how it should be carried out. Problematically for nanotechnology, regulation is complicated by the complex nature of the technology, as well as wider social constructions that confuse and complicate many issues. This is as well as a general difficulty with a lack of scientific data to support regulatory decision-making and recommendations. This is not to position scientific data as prime, but more to highlight the difficulties where data can be pivotal for areas such as product safety, and problems that ensue when it does not at present, often exist. Thus the ability to engage with nanotechnology as a high technology product class is severely limited, and is acknowledged throughout this chapter.

As a starting point from which key themes and ideas are drawn out and built on, the next section considers regulating high technology.

7.2. Regulating High Technology

Novel high-technology products present many opportunities and challenges for businesses and the regulatory structures engaged with commercialisation-based activities. Through the broadest lens, regulatory structures can either help or

hinder commercialisation and safeguard or damage the marketplace and environment. Depending on the scope of legal regulation, it can shape the R&D landscape, commercialisation, as well as other socio-economic and physical environments. Regulating any technology is arguably a double-edged sword in that it can protect societal interests, but at the same time stifle innovation and increase barriers to commercialisation. The challenge for regulators is to understand the phenomenon they seek to regulate in an in depth enough way to engage meaningfully with potential outcomes, which is no small undertaking. If regulations are too strict, or are based on information that is incomplete or with an excessive precautionary principle, they have the potential to distort the market and delay technological benefits to society. Alternatively, if regulation is too lax, this can also result in the commercialisation of toxic products.

Within these socio-organisational and regulated structures are different stakeholders including individuals, companies, and interest groups that all produce their own narratives and can make the environment of commercialisation opaque for individuals carrying out decision-making. This can be even more pronounced in high technology areas such as nanotechnology, where the commercial environment is complex and often uncertain (Falkner *et al,* 2012). Importantly, regulatory barriers can arguably be segmented into the real and the perceived. Although a blunt segmentation, real regulatory barriers might for example seek to obligate manufacturers to health and safety testing, which can delay the commercialisation of a product, and increase the cost.

Regulation can be carried out from the micro-scale i.e. self-regulation (micro) and at the other end of the spectrum at the macroscale via top-down external regulation (macro), including regulatory bodies, with both being examined in this study. Simplistically, it has been argued that with no or limited regulation, a business ‘free for all’ can be created where ‘anything and everything’ can be commercialised irrespective of the consequences (Jones and Hunziker, 1994). Thus there is a balancing act between regulating between competing aspects such as safety, while enabling commercial activities to meet societal and economic demands, that benefits companies, society. The question of who should construct and operate a governance system is wide ranging, and in this study, there is an

examination of different regulatory systems, which include many types of organisations including governments, interest groups and self-regulation.

To further understand these aspects in light of nanotechnology, the next section explores regulating nanotechnology.

7.3. Regulating Nanotechnology

This study has discussed some of the most important challenges of the physicality and socially constructed aspects of nanotechnology, with this section exploring the regulation of this area, and in particular nanoparticles. This is no small task due to the complexity and opacity of the subject matter. Importantly, this is being carried out in over sixty countries, where politicians, academics, regulators and members of the public have been asked questions about the long and short-term adequacy of existing nanotechnology regulation to better inform decision-makers about how nanotechnology should be regulated, if at all (RS and RAE, 2004; Macoubrie, 2005; Chaundry *et al*, 2006; Gavelin *et al*, 2007; Hansen, 2009).

There are multiple views on nanotechnology-based regulation, and how existing principles may apply, if at all, which in part can be linked to difficulties for stakeholders to actively engage with nanotechnology and make sense of it. More than being a nanotechnology problem, this is an issue potentially experienced with any new technology, but is arguably more pronounced with nanotechnology. This has resulted in a broad spectrum of approaches being suggested, which range from a 'laissez-faire' attitude all the way through to 'overhauling' different regulatory systems. More broadly though, there are concerns about the capacity of governments and regulators to respond to and address the challenges that nanoscale substances and innovations may bring (Bosso, 2010). This is based on there not being a clear understanding of how regulation will affect or indeed is affected by nanotechnology, or more pertinently, what exactly nanotechnology is, thus how to regulate it.

Arguably, the regulation of nanotechnology will be in an arena of much uncertainty (Bosso, 2010). Regulators may need to be flexible and adaptive, taking evidence based approaches so that innovation and trade is not hindered but human health and safety, and the environment is protected. Nanotechnology should not be thought of as harmful or benign unless there is supporting scientific evidence. Therefore problematically, any nanotechnology regulation will not only be made against a backdrop of uncertainty, but also against *'a reasonable level of* [unknown] *risk'* creating challenges for decision-making. It is foreseeable that due to a lack of understanding and information available on nanoscale substances, regulation may need to be created before all the evidence can be provided (Eisner and Coglianese, 2010). This is due to the nanotechnology market developing at a faster rate than science testing can elucidate risks, and a lack of a coherent strategy within science to understand the risks hereafter (Bosso, 2010). Eisner (2010) has argued that the lack of specific information from science is the greatest problem for regulation. This may hinder regulators in their quest to understand the consequences of health and environmental exposure or the key contributory mechanisms that could prevent the 'correct' regulatory response.

Discourse on nanotechnology regulation has often stated a need to produce a uniform approach to a myriad of products spanning 'all' sectors. There has however been little suggested for how to achieve this (Macnaghten *et al*, 2005). Fundamentally, one of the greatest challenges facing nanotechnology regulation is whether to regulate on the basis that nano is 'smaller' than bulk products, or functionally different. If simply smaller, nanotechnology may sit easily within current regulations, which potentially cover this collection of products. If functionally different, current regulations may need modification.

Importantly the argument has been made that: *'Despite some earlier concerns that the use of nanomaterials in food was essentially unregulated, it is clear that nanotechnologies in food are regulated'* (Sanderson, 2013: WP). Looking at this comment, it is worth pointing out that it is not that nanotechnology sits outside of all regulatory systems, but more that the physicality of the phenomenon of nanotechnology is not well captured by current regulations. Drawing on the work

of Davies (2006), it was argued that there are so many combinations from the physicality of nanomaterials (including size, shape, chemical reactivity and material composition), the need for deeper examination is clear, particularly for toxicity. For example there are up to 50,000 different permutations possible just from one single-walled carbon nanotube which points to regulation being a daunting task, but never the less, an essential one. Davies (2006: 14) also makes the pragmatic claim that there are regulatory implications for difficulties in detecting nanomaterials: *'if these nanomaterials cannot be detected, the provisions of the environmental laws are inoperable'*. Thus, an argument can be made that regulation may well need to be linked with further exploration and exploitation of technologies to more adequately interrogate nanomaterials.

Suggestions for nanotechnology regulations were made by Kimbrell (2009) who claimed that nanotechnology has highlighted how 'out-dated' our current regulatory systems are for high technology and how ill equipped they are to deal with high technology issues of the twenty first century. Although specifically orientated towards high technology, it must be remembered that regulatory systems are in a temporal state of flux, where what is desirable and fit-for-purpose today may not be tomorrow. More than this, technology, and particularly high technology, creates challenges for the way that stakeholders perceive specific aspects as 'bad' or 'good', and as cultural drivers for technology change, so potentially their narratives, necessitate different regulations, built upon different foundations.

Looking at the suggestions by Kimbrell (2009), eight principles for developing regulations were put forward and are shown in Table 7.1.

Number	Principle
1	A precautionary foundation.
2	Mandatory nano-specific regulations.
3	Health and safety of the public and workers.
4	Environmental protection.
5	Transparency
6	Public participation
7	Inclusion of broader impacts – ethical and social.
8	Manufacturer liability.

Table 7.1. Suggested eight principles for good governance.

These principles discussed in the above table 7.1 potentially make a good basis for taking the first steps towards nanotechnology regulation although it must be remembered that nanoparticles potentially can change their physicalities making strict regulatory systems highly challenging.

An 'ideal' solution as a foundation for the regulation of nanoparticles and nanotechnology would be to use the precautionary principle as a basis, so that any threat to human health and/or the environment can be minimalised. This maybe necessary even if some 'cause and effect' relationships have not yet been fully established by the scientific community due to the lack of data in this area (Kimbrell, 2009). The precautionary principle is often viewed as part of or an alternative to risk management strategies, where the burden of proof for safety falls upon the product manufacturers and distributors with lack of evidence of specific harm or data not being a substitute for reasonable certainty of safety. Unfortunately no version of the precautionary principle answers the critical questions that need to be considered in moving forward with regulatory decisions for nanotechnology, such as; what level of harm is required to trigger the principle, what level of risk is acceptable, and how should risks and benefits of a new technology be weighed up (Marchant, 2003). Guidance in these areas is not provided by the principle (Sunstein, 2003). Yet the precautionary principle can be useful as a regulatory tool for nanotechnology if used as a precautionary foundation. This approach can be implemented by making it a pre-requisite for market approval that independent health and safety data reviews are carried out

with all information recorded for future reference in a data-base or registry, by the monitoring and recording of results over time, particularly data associated with worker exposure.

For any nanotechnology regulatory regime to be effective the legal authorities must be modified and adaptable so that the different properties and challenges presented by the nanoparticles can be effectively and adequately addressed. Unfortunately any regulatory system would still be inadequately equipped to oversee future processes and products such as nano structures and active nano systems currently under development (Kimbrell, 2009), but as a starting point to build future regulatory regimes upon, this can be seen as a step forward in the right direction. In other words, it might be argued that some regulation is better than no regulation, particularly if that regulation is flexible and adaptive. Part of this regime would be that nanoparticles would be treated as separate substances to their bulk counter parts, allowing them to be regulated under nano-specific mechanisms, which require specific testing and data requirements. This should be mandatory as voluntary initiatives are often insufficient due to lack of compliance and therefore create data gaps, which often delay mandatory measures (Brazell, 2012).

When setting out a regulatory regime for nanotechnology and nanoparticles the health and safety of humans and the environment should be paramount. Therefore it could be argued that any nanomaterial that has not been proven safe to humans or the environment should be removed from the market place, although this would no doubt be much criticised by manufacturers. As I believe that the precautionary principle should be the basis for regulation, the ‘active’ form rather than the ‘strict’ form should be adhered to, which is discussed further in section 7.3.1.3, allowing the benefits of nanoparticles and nanotechnology to be further considered until proven unsafe. The issues of health, safety and the environment are discussed in more detail in Chapter 6.

So far products containing nanoparticles have been commercialised without their full life cycle analysis being fully investigated. This could lead to unknown environmental impacts from inception at the manufacturing stage through to

usage and disposal and into the waste stream. To protect the environment from possible nanoparticle toxicity, a full life cycle analysis should be completed prior to commercialisation of a nanoparticle product. To help with this, government funding must be increased for environmental impact research, which should couple laboratory and 'real life' scenarios. To coincide with this, existing environmental protection laws, assessments and metrics must be adjusted and made adaptable to address the new challenges brought by the potentially changing physicalities of nanoparticles. These issues are discussed in more detail in sections '6.4. Environmental Issues' and '6.5. Uncertainties of Environmental Exposure'.

A key feature when installing a regulatory system for nanotechnology is transparency to ensure that measures are put in place for adequate protection for the public, workers and the environment. Workers have a 'right to know' what they are working with and the dangers so that the correct procedures are carried out if necessary. For example a spillage may need to be documented correctly and the appropriate measures taken to prevent toxicity. Product labelling should be mandatory, not only in the workplace but for all products that contain nanoparticles. As already stated this can be problematic as manufacturers may buy products from abroad from companies who are not as rigorous when it comes to identifying ingredients. Therefore I would suggest an international standard for labelling, with recommendations for companies to buy from other companies who adhere to this standard. Another problem with regards to labelling is the label itself. By saying 'nano' after the nanoparticle ingredient can mean nothing if the reader of the label has no idea what 'nano' means. Therefore public perception of nanotechnology becomes the key issue here. For those who believe that nanotechnology is a positive thing, having nano ingredients can be an important selling point. For those who believe that nanotechnology has negative aspects, consumers may believe by using products containing nanoparticles could reduce sales. I would suggest therefore that writing 'nano' on a product on the ingredients list to show that nanoparticles are present is meaningless until the public become better informed about the potential benefits/hazards associated with nanoparticles. This leads me to suggest that for greater transparency, the government should provide the public with more

information about nanotechnology so that the public can make better-informed choices about products they use. This data would be updated as and when new data is established.

Another important issue is that safety data should be made available for public scrutiny and strictures placed on the use or misuse of confidentiality shields (Kimbrell, 2009). The suggestion by the European Commission to create a web platform with references to all relevant information sources, which would include registries and data-bases would imply that there is a need for better accessible information and increased transparency (Europa, 2009). This analysis will also include those nanoparticles that currently sit outside the existing framework of notification, registration or authorisation schemes, by lowering the One Tonne Limit in REACH to a realistic limit such as 100 g, the limit for notification for the French registry. This is discussed further in section '7.3.6.1. The Objectives of a Registry'.

Public participation must become more open and meaningful from all interested and affected parties, such as government and corporate alliances to be able to create a more workable regulatory system for nanotechnology (Kimbrell, 2009). All processes and discussions must be driven by social needs, which are identified through informed deliberation instead of false presumptions of technological inevitability for benefit.

When forming the principles for good governance, it is also important to look at the wider impacts from the wide-ranging effects of nanotechnology including the social and ethical implications, which must be considered (Kimbrell, 2009). A full debate on the potential impacts of the 'next generations' of nanotechnologies is necessary due to their complex risks and potential ethical and social challenges. A suggested way forward is through adequate government funding to provide the social sciences the means to analyse nanoparticle implications alongside the health and environmental sciences.

Companies that manufacture nanoparticle products should also be part of the regulatory scheme due to the monitoring and recording of data associated with

their manufacture, as well as part of their duty of care towards their employees. When examining a manufacturer's liability, a manufacturer or seller of a product generally would not need to warn the public about the contents of their products unless the contents could put the public at risk of harm. Warnings would be expected on products that could cause risk allowing the consumer to choose whether to purchase/use the product or not. Unfortunately because of the uncertainty surrounding nanoparticles, manufacturers are in a difficult position. They have a duty to instruct users on the safe use of their product. Companies also have a duty to report any reasonable suspicion of a material appearing to pose a threat to human health or the environment at the earliest opportunity. If the manufacturer or importer has completed a checklist with REACH to the best of their ability, due to the substance being hazardous or over the one tonne limit, they would gain protection against legal action if the nanomaterial subsequently proved to be harmful in some way. Currently nanoparticles are treated the same as their bulk counter part and are regulated as such but it is my opinion that manufacturers should keep up to date with scientific knowledge, advances and discoveries as well as test and monitor their own products. Therefore I believe that it is the duty of the manufacturer to raise concerns about a product that they may deem unsafe rather than rely on testing by another company.

These suggested eight principles form a basis for good governance for a basic model for nanoparticle regulation. They are based on the precautionary principle, which allows the development of nanoparticle products with caution alongside stringent monitoring and recording systems. They are by no means a 'silver bullet' but they are a step in the right direction if nanotechnology is ever to be regulated.

There has been much varied discourse being generated from within the UK and outside sources penetrating into 'national' discourse, with many views about regulating nanotechnology. It was however the Royal Society and Royal Academy of Engineering report (2004) 'Nanoscience and Nanotechnologies: opportunities and uncertainties,' that prompted a review by HSE, to examine the current regulations in relation to nanoparticles. The interesting point here to note

is that this report was made in 2004 and so far to date (2016) there has been no update.

All recent and available information on nanoparticles was reviewed by HSE to access the physicochemical and toxicological hazards that can occur as a result of workplace and occupational exposure. During this process, it was noted that little research existed on novel nanoparticles, but more on materials that had been downsized to the nanoscale. While the UK Government has since accepted these recommendations it has to date not implemented them (HSE, 2004). Importantly, the findings from this study strengthens an understanding of the reductive process of miniaturisation but unfortunately offers less knowledge for novel materials produced from other techniques, and potentially drives a regulatory view of nanotechnology products as just being downsized materials.

The next section deals with REACH, the current regulatory framework on health and safety hazards and risks in the work place that has been standardised across the EU and the UK.

7.3.1. REACH

In the EU, the body known as Registration, Evaluation, Authorisation and restriction of CHemicals (REACH) came into force on the 1st June 2007 as a chemical regulator. REACH is constructed towards the labelling, classification, use, restrictions and marketing of all new chemicals and the management and assessment of existing chemicals. There are five main aims that REACH is engaged with which are shown in Table 7.2.

Number	Aim
1	Provision of a high-level of protection of human and environmental health and safety from chemical usage.
2	Ensure that manufacturers and importers of chemicals for the market place understand and manage the risks associated with their use.
3	To allow substances in the EU market to have free movement.
4	To allow the chemical industry in the EU to be enhanced by competitiveness and innovation.
5	To allow a choice of methods of assessment of the hazardous properties of substances.

Table 7.2. Five aims of REACH.

REACH applies to substances imported into or manufactured in the EU in quantities of one tonne or more per year. It applies to all individual chemical substances on their own in preparations, or in articles (Ward and Harley, 2010). There are some exceptions such as radioactive substances, waste, plant protection products and biocides, and human and veterinary medicines.

When REACH came into force in 2007 it established a new authorising system requiring *'registration and evaluation of existing and new chemical substances'* (EP and CEU, 2006: WP) and new chemical legislation for the commercialisation and manufacturing of chemical substances for the EU market. This registration process compels importers and manufacturers to collate information on the substances that they import, produce or use. Information is then used to assess potential hazards and is added to a registration dossier that is sent to the European Chemicals Agency (ECHA), where the properties of the substance can be assessed for any risks to human health and/or the environment. Risk management strategies can subsequently be developed for the various uses of the substance (Ward and Harley, 2010). This moves the responsibility from authorities to industry, with regulation prohibiting manufacture or sale of any substance in the EU that has not been registered with ECHA, providing that one tonne or more is sold per annum.

To be compliant with REACH, all chemical suppliers (above one tonne) are required by EU directives to find and provide information to the recipients of goods on physicochemical and toxicological hazards that are present in their chemicals. This directive comes under the EU Standardised Classification and Labelling (C+L) and the Safety Data Sheets (SDS). Standardised testing of industrial chemicals for hazardous properties that are new to the market must also be undertaken. Recipients can use this information to assess and manage workplace exposure to any hazardous chemical, to reduce and minimise health and safety risks (HSE, 2004).

Many substances have already been marketed without having their properties being investigated because they are less than the one tonne per annum. Legislation requires that suppliers must produce a set of information detailing the properties of a new substance before it goes to market, which is known as the Notification of New Substances (NONS) (HSE, 2004). The database of existing substances, referred to as the European Inventory of Existing Commercial Chemical Substances (EINECS) label substances already on the database as *'existing'* and any substance that is added later as *'new'* (HSE, 2004). It is the responsibility of the supplier to investigate a substance and determine if it is on the EINECS. HSE (2004) has argued that REACH will be key for developing new legislation that will have major consequences for nanotechnology, although at the present time REACH does not directly address nanomaterials as a distinct phenomenon, only through prior technological lenses. Importantly, this may well be based on whether a nanomaterial will require NONS, which can be based on the one tonne limit.

Chaundry *et al* (2005) has identified gaps for environmental regulation in both the EU and the UK, with regards to the question of whether a nanoscale substance was equivalent to its bulk counter part or named as a new substance under REACH. REACH (Leeuwen and Vermeire, 2007: 64) defines a new substance as:

'A chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.'

How nanoparticles are perceived will determine whether different hazard information needs to be produced on the registration dossier if these materials are over the one tonne limit for the year. If nanoparticles are believed to be the same as the registered bulk material then all hazard information data would need to be discussed (Chaundry *et al*, 2006).

Questions are being raised by many stakeholder groups including the European Trade Union Confederation (ETUC) and Friends of the Earth Europe over the uncertainty and inadequacy of regulations associated with the nanotechnology industry. This has been attributed to nanomaterials being covered by the regulation's definition of chemical substance, which may not be the 'best' definition. Therefore it is necessary to examine how REACH defines a chemical substance, which is considered in the following section 'Definition of a Chemical Substance'.

7.3.1.1. Definition of a Chemical Substance and Nano

Importantly there is no provision in REACH that applies directly to nanomaterials. Under REACH, all chemical substances need to be registered yet no specific nanomaterial can be registered, even though core materials such as silver, titanium dioxide, carbon and gold are (O'Brian, 2012). This poses the question as to whether nanomaterials are to be considered the same or different to the bulk material? And does REACH regard them as the same? This is a pivotal question for regulators and manufacturers. Either way, it will have a major impact on manufacturers' requirements prior to market placement. If a nanoparticle were to be treated as a different substance, then hazard information

would have to be produced for the registration dossier (if the substance is of one tonne or more per year.) Yet if the substance is classed as equal to the registered bulk material, then the hazard data would be given as the same but this is open to debate due to nanomaterials having different properties to their bulk counterparts (Chaundry *et al*, 2006).

The definition of a *'chemical substance'* as defined by Article 3 in REACH: (ECHA – 11 – B – 10 –EN, 11/2011: WP)

> *'A chemical element and its compound in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.'*

The definition appears to be wide ranging and almost all encompassing and clearly goes beyond regulation of pure chemical compounds produced naturally or synthetically. The term covers both substances obtained by a manufacturing process and substances in their natural state and which can both include several constituents within the substances and be taken into account as far as possible when identifying the substance.

It could be argued then that nanomaterials are regulated by REACH due to being covered by the definition of a chemical *'substance'*, although there are no explicit regulations or specific mention of nanomaterials (Europa, 2009). A review by the European Commission, published in 2008, (CEC, 2008) argued that although there is no specific mention in REACH of nanomaterials *'a chemical substance'* includes them (CEC, 2008a). It goes on to state that when an existing chemical substance, already placed on the market as a bulk substance, is introduced to the market in a nanomaterial form (nanoform), the registration dossier will have to be updated to include specific properties of that substance. The additional information, including different classification and labelling of the nanoform and additional risk management measures, will need to be included in

the registration dossier. The risk management measures and operational conditions will have to be communicated to the supply chain (CEC, 2008a).

The Commission Communication on the 2nd Regulatory Review on Nanomaterials (October 2012), as well as the REACH Review (February 2013) concluded that REACH and the CLP (classification, labelling and packaging) offer the best possible framework for the risk management of nanomaterials when they occur as substances or mixtures. However it has proven necessary that more specific requirements for nanomaterials are needed within this framework. The Commission is therefore considering a modification of some technical provisions in the REACH Annexes and a public consultation has been launched to this effect that from the 21st June – 13th September to increase dialogue to aid in this area (ec.europa, 2013).

Nanomaterials that fulfil the criteria for classification as hazardous under Reg. 1272/2008 on CLP of substances and mixtures must be labelled and classified. This applies to nanomaterials in their own right, or as nanomaterials as special forms of the substance. Many of the related provisions including safety data sheets and classification and labelling apply already today independently of tonnage in which the substances are manufactured or imported.

Until recently there was no specific guidance by ECHA concerning nanoparticles. Information on nanoparticles was included in a technical manual in an IUCLID (International Uniform Chemical Information Database) dossier that was part of each REACH registration. Best practises were included on nanoparticles as well as any nanomaterials information. This is particularly important when nanoparticles are not substances in their own right, and are part of or mixed with substances.

Compounding the problem for companies seeking guidance on nanotechnology and nanoparticles there are no up to date guidelines for companies to follow. Existing guidelines that support REACH may not be appropriate for nanoparticles and their possible risks (SCENIHR, 2007; CEC, 2008a). Importers and manufacturers may be required to carry out a safety assessment if they

exceed 10 tonnes in volume, as the equivalent bulk material's toxicological profile may not be reliable. If quantities of one tonne per annum are produced, companies must register these materials. Therefore it may be more appropriate to develop an early warning system so that all importers/manufacturers of nanomaterials or products containing nanoparticles would be required to complete a standard checklist. This would be designed to focus on the functionality of the nanoparticles and explain why they have been produced and incorporated into the product. Monitoring the pathways of human and environmental exposure throughout the product's life cycle would need to be considered. The next section discusses the One Tonne Limit and the problems when trying to regulate nanoparticles under these guidelines.

7.3.1.2. A One Tonne Limit

The one tonne limit is the point where companies must register materials that are produced or imported, with a chemical safety assessment being required alongside risk assessments (C and EN, 2008). Importantly, chemical substances manufactured or imported in weights less than one tonne are exempt from this process, mitigating such manufacturers and importers from this obligation and a need to provide environmental exposure assessments or toxicological data. This raises a pivotal question for companies engaged in nanotechnology, should their products be required to undergo REACH assessment, as many might not have the required weight? (Chaundry *et al*, 2006; Franco *et al*, 2007). Chaundry *et al* (2006) suggested that the majority of nanotechnology products are of a low, sub-one tonne weight and therefore will automatically fall outside the scope of REACH. For novel non-miniaturised nano-engineered products, the likelihood for REACH assessment is even lower, particularly where the nanomaterial constituent is lower than 0.1 percent of the final product and no registration is required. However, as Franco *et al* (2007) argued, there is a general lack of information and transparency concerning nanoparticle concentration and product formulation leading to substances of undetermined concentrations by weight, further complicating this aspect. This has given concern to the European Commission who states that if a substance is below the tonnage threshold but is

of a high enough concern then an authorisation and restriction process must be put into place. Currently REACH's policy states that materials of concern must have authorisation for use and before market entrance (SCENIHR, 2006; ETUC, 2008). The opinions of SCENIHR and ETUC could put pressure on REACH to place further restrictions on nanomaterials until further investigations into HSE take place.

The French Registry for nanomaterials believe that the one tonne limit in REACH is far too high and have lowered it to 100 g of substance at the nanoscale, produced, imported, or distributed during the previous year, that must be registered and submitted to the French National Agency for Food Safety, Environment and Labour (safenano, 2014). This is still a large amount of nanoparticles but it will ensure that the substances that reach this limit will be authorised and registered. In my opinion, a lower threshold of 50 g would be more appropriate but any weight limit should be evidence based. This also suggests that the French government see nanoparticles as different substances to their bulk counterparts.

Importantly, and an area often overlooked within REACH, is that nanomaterials properties may change over time. In other words, their size and shape (leading to changes in weight) may fluctuate, resulting in further complications to regulation. In such circumstances, regulators must decide a course of action in the face of such uncertainty (Porter, *et al*, 2011). While it has been argued that the move to more nuanced regulation is possible, it has also been stated that regulators lack the basic information needed to enable more fit-for-purpose decision making (Porter *et al*, 2011).

Although there are recognised challenges for the one tonne limit, EC funded research in 2008 has started to address methodologies for identifying hazards of nanoscale substances through the 7th Research Framework Programme (FP7). Shatkin (2008: 144) stated that:

> *'It will be necessary to carefully monitor over the next few years whether the* [one tonne per year*] threshold for registration and the*

information requirements under REACH are adequate to address potential risks from particles on a nanoscale.'

With so much ambiguity about no requirement to test below the one tonne limit, ECHA suggested a *'no data, no market'* principle should be adhered to in REACH. This would prohibit chemicals without data to support their safety from being registered, and make a step to address the difficulties faced from the one tonne limit. In this scenario, REACH would have the data before commercial manufacture, marketing and the use of nanoparticles to limit harm to human health or the environment. ECHA also believes that industry needs to be encouraged to fill some of the gaps in scientific knowledge for the safety of nanomaterials, particularly any knowledge of the fate and persistence of nanoparticles in the area of HSE (ETUC, 2008). Under the current system of the one tonne limit, this can only be a suggestion at the present time.

Within discourse about the one tonne limit, there are many repetitive themes in respect of nanomaterials. Thus without changes to establish more fit-for-purpose regulation continued arguments will be made towards responsible commercial practice, particularly in sectors where organisations have opportunities to act irresponsibly in order to gain competitive advantage or where current legislation is not designed to protect against unexpected risks. An example of this would be the cosmetics industry via the existing Cosmetic Directive, (76/768/EEC) where all cosmetic products must undergo a safety assessment to be 'safe' for consumer use before being placed in the market place. There is however no specific reference or safety assessment for nanomaterials (National Archives, 2011), which may create the view that since testing has been carried out products are safe. Thus a precautionary testing approach must be coupled with fit-for-purpose testing.

In the following section, the precautionary principle is explored as a regulatory system to induce safety, with consideration being given to this aspect in and outside of REACH.

7.3.1.3. The Precautionary Principle

With many aspects of novel products not being knowable at the time of commercialisation, arguments have been made that a '*better safe than sorry*' approach should be taken (DiGangi, 2004). REACH for example is based upon this principle, which simply can be regarded as being '*the precept that an action should not be taken if the consequences are uncertain and potentially dangerous*' (Collins English Dictionary [Digital Edition], 2009: WP). A more technical definition can be taken from The Precautionary Principle Website (2015: WP):

> *'When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm. Morally unacceptable harm refers to harm to humans or the environment that is:*
>
> - *Threatening to human life or health;*
> - *Serious and effectively irreversible;*
> - *Inequitable to present or future generations;*
> - *Imposed without adequate consideration of the human rights of those affected'*

This guiding principle requires manufacturers and industries to provide information concerning the safety of chemicals, and restricting or preventing the use of the most dangerous before they are placed on the market. While this may appear a straightforward task, considering the numerous problems of opacity and paucity of data for nanomaterials, this is potentially far more difficult than it may at first appear. Although REACH is based on the precautionary principle, the problem is created by the belief that nanomaterials are the same as their bulk counterparts. REACH adheres to a *'no data – no market, no data – no risk'* policy, which is certainly problematic. More that this though and looking again at REACH, the precautionary principle has no set standard text and many of the suggested formulations differ in important aspects (Sandin, 1999). Also there is no version that answers the serious questions that are necessary before moving forward to make regulatory decisions (Marchant, 2003). This includes scenarios

such as the level of risk that is acceptable, how can benefits be weighed against risks when using technology, and which types of data is suitable for a manufacturer to submit that will satisfy the principle (Marchant, 2003).

Unfortunately, if there are no specific guidelines or criteria to answer these questions then the precautionary principle could be prone to capricious or arbitrary decision making, as well as the potential for mischief making. An example of this is the prohibition of the sale of cranberry juice containing vitamin C in Denmark due to scientific uncertainty from a possible over enrichment of vitamins (Marchant and Mossman, 2004). Denmark argued that there was no nutritional need for this type of food, as their population was not lacking in a vitamin deficient diet. 'Ocean Spray' who is a maker of cranberry juice, complained to the Commission of the European Communities, who stated that Denmark had violated Article 28 of The Treaty Establishing the European Communities that prohibits quantitative trade barriers. Denmark had used Article 30 of the Treaty to avoid the effects of Article 28, permitting a trade restriction due to their belief it could harm human health. The commission stated that this argument by Denmark was inapplicable so Denmark refused the sale of the Cranberry juice because of inadequate labelling (Harrington, 2006).

The precautionary principle is often brought into play when the situation in question has the potential to become hazardous (Phoenix and Treder, 2003). According to Phoenix and Treder at the Centre for Responsible Nanotechnology, there are two forms of the precautionary principle, including (1) the strict form and (2) the active form. The 'strict' form necessitates inaction, when taking action may pose a potential risk as described by Phoenix and Treder (2003: WP):

> *'The principle, itself a topic of debate, was designed to reduce environmental and health risks by limiting scientific exploration when its impact is in doubt.'*

The 'active' form involves the choice of alternatives that are 'less risky' when and if they are available and also includes taking responsibility for any potential

risks that may arise. This is set out in the Rio Declaration on Environment and Development, which states in Article 15 (WP):

> *'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost – effective measures to prevent environmental degradation.'*

Looking at this more bluntly, precautionary measures should be taken even if there is a lack of certainty, as inaction may result in harm. However the strict form of the precautionary principle would argue that inaction is preferable if taking action will cause more harm (Phoenix and Treder, 2003). This is clearly a difficult decision-making process and one that should where possible be based on 'best' evidence.

The Precautionary Principle in the 'active form' urges a more dynamic approach rather than a cautionary one (Tickner *et al,* 1999). Less risky alternatives need to be sought with suitable efforts made to mitigate any potential risks. As Phoenix and Treder (2013: WP) stated that: '*The litmus test for knowing when to apply the precautionary principle is the combination of threat of harm and scientific uncertainty*'.

An argument can be made that the precautionary principle should be used when dealing with nanomaterials due to the claim that some nanomaterials can cause lung cancer, heart and lung disease and even death (Donaldson *et al,* 2005). Warheit *et al* (2004) have however suggested the following difficulties without the guidance of the precautionary principle, shown in Table 7.3.

Number	Difficulty
1	The burden of proof lies with the government to prove that there is a potential for harm due to *'no data – no risk.'*
2	Under the REACH regulation, the threshold for registration of chemicals is 1 tonne but nanomaterials have the potential to fall under this threshold because of their small size.
3	The regulations that are in place target the chemical not the 'end product,' the usage or the product at the end of life stage where nanomaterials may become unbound and be released into the environment.
4	Currently there is no equipment able to detect nanomaterials in the environment or the workplace, which leads to a lack of ability to enforce regulation.

Table 7.3. Difficulties Without the Precautionary Principle.

With evidence to suggest that single walled nanomaterials have the ability to cause toxic damage to humans, Warheit *et al* (2004) have argued for a precautionary approach to be taken. If followed, Manson (2004) has suggested the following benefits shown in Table 7.4.

Number	Benefit
1	Prohibit untested and potentially unsafe chemicals from being released into the market place.
2	Inhibit assessments for EHS would become a prerequisite before commercialisation
3	Nanomaterials would be assessed as new substances and not their bulk counterparts as they have unique physical properties that have distinctive hazard properties.
4	An assessment of the social and ethical consequences of the impacts of nanotechnologies would take place.
5	Workers and communities would have more protection.

Table 7.4. Benefits With the Precautionary Principle.

The precautionary principle could create a more appropriate guide for implementing nanotechnologies yet there are still many aspects needing to be considered before such an approach can be made workable. Currently neither the precautionary principle nor traditional methods of risk management are acceptable methods for nanotechnology regulation (Wilson, 2006; Florini *et al,* 2006; Lin, 2007). ETUC acknowledges that there are significant uncertainties surrounding nanotechnologies and their benefits to society (ETUC, 2008). They realise that nanotechnologies have the potential to inflict harm on human health and the environment therefore they want the precautionary principle to be applied to all nanotechnologies.

As previously discussed in section '7.3. Regulating Nanotechnology', the precautionary principle could be used as a basis for a precautionary foundation regulatory regime. By proceeding with caution and with careful monitoring and recording of all nanoparticle testing and product data, the precautionary principle could be a useful regulatory tool for nanotechnology. As no version of the precautionary principle answers the critical questions that need to be considered in moving forward with regulatory decisions, such as; what level of harm is required to trigger the principle, what level of risk is acceptable, and how should risks and benefits of a new technology be weighed up, I suggest a cautionary approach to allow the development of new technologies and minimalise risk.

Considering the challenges raised in this section of the precautionary principle, the next section moves on to examine the control of substances hazardous to health, through which some aspects of regulation of materials can also be achieved.

7.3.4. The Control of Substances Hazardous to Health

The control of substances hazardous to health 2002 (COSHH) is a UK based statutory instrument that obligates employers to protect their workers and other persons from exposure to substances hazardous to health. COSHH encompasses many vehicles for reducing potential harm, through risk assessments, control of

exposure, health surveillance as well as incident planning. Arguably, COSHH sets a minimum standard determined by employers, who are responsible for implementation. From a broad perspective COSHH enables many aspects to be considered and internally regulated. Unfortunately, the paucity of knowledge for nanomaterials and nanoparticles creates challenges for producing 'adequate' COSHH assessments (HSE, 2004). As stated by HSE (2004), there are three main failures based on a lack of knowledge for nanoparticles as shown in Table 7.5.

Number	Perceived failure of knowledge
1	Insufficient toxicological and hazard information for most nanoparticles.
2	No reliable or cost-effective measurements for standard exposure.
3	No agreed or standard definition on an appropriate dose that can be used in a hazard study.

Table 7.5. Perceived failures in knowledge for nanoparticle COSHH.

Perhaps one of the greatest challenges for COSHH and nanotechnology is the expectation for employers to have knowledge capable of determining what procedures to carry out for what is a highly complex and technological area.

Advice from HSE (2004) suggested that nanoparticle dust can be hazardous at or above 4 mg/m^3 and that workers must be protected against it. Coupled with a difficulty of measuring nanoparticles in the working environment, is the arguably greater problem that personal protective equipment (PPE) is known not to be effective. Thus the question can be asked, what should be done about nanotechnology phenomena such as this? The Royal Society and The Royal Academy of Engineering Report have suggested that occupational exposure limits for manufactured nanoparticles should be lowered, which in part addresses some of the concern. They base their evidence on current legislation in the UK that allows a workplace exposure limit (WEL) assessed on the mass of inhaled particles (larger sized particles). They claim that if a worker becomes exposed to a mass of inhaled nanoparticles, this would be a vast amount, putting the worker at potential risk. Therefore the current WEL may not be sufficient protection

against exposure to inhaled nanoparticles. HSE (2004) states that there is not enough data to change the WEL at the present time and that there are no practical methods available for measuring personal exposure in the workplace. Machinery is too bulky or large, therefore creating a need for portable equipment. Currently (2016) there is still not enough data and any portable measuring equipment has proven inadequate.

Further to these issues, when examining the COSHH health surveillance, HSE (2004) claimed that there is not enough information to assume that nanoparticles cause health risks, thus no valid assessments can be made. This is a disconcerting view as not having enough information is not the same as not having any information. Again, this can impact on employer decision-making for what to do in these circumstances.

When assessing the use of nanoparticles under the Dangerous Substances and Explosive Atmospheric Regulations (DSEAR), HSE (2004) states that it is impossible to predict nanoparticle properties based on 'facts' taken from studies of larger sized particles. Better understanding of nanoparticle uncertainties particularly in the area of flammability and explosivity, is therefore needed by the user (Pritchard, 2004).

This section has again highlighted the challenges for decision-making against a backdrop of adequate and fit-for-purpose information. In the following section a different vehicle for regulation is considered, which is the international organisation for standardisation.

7.3.5. International Organisation for Standardisation

As previously mentioned, there are many types of voluntary regulatory systems that can be adopted by organisations, with a further example of this being the International Organisation for Standardisation (ISO). ISO sets environmental management system standards and is made up from 'national standard bodies' from over one hundred countries (Coglianese, 2010). It has developed over

10,000 standards since its formation in 1947. An environmental management system (EMS) can produce benefits for a company as well as providing benefits for society as a whole by allowing policymaking to be implemented by the organisation or business internally. Importantly, and while REACH has not specifically addressed nanotechnology, ISO has moved to examine nanotechnology, and nanoparticles through ISO 10808: 2010 Nanotechnologies Characterisation of Nanoparticles in Inhalation Exposure Chambers for Inhalation Toxicity Testing. This is a set of guidelines to help industry assess risks due to the growth of nanoscale-based products and was published to ensure that any results from airborne toxicity analysis would be generalisable amongst the global community. There are four main areas that have been considered in ISO 10808: 2010, on a self-regulatory basis and are shown in Table 7.6.

Features	Description
Performance standards	A performance limit is specified, which workers cannot be exposed beyond to a specific hazardous chemical, although no advice is given for how to achieve this (Viscusi, 1983). Flexibility of methods is enabled thus allowing companies to find cheap methods to attain the required performance level (Gunningham, 1996), and may expose workers due to poor methods being selected. Arguably, self-regulation is open to abuse if not monitored correctly. For example, if those regulating the performance standards do not posses the appropriate monitoring equipment or it is deemed too costly to measure the performance of a number of companies, workers may be exposed.
Emission thresholds	Thresholds can be set to prevent human health or environmental risk and fines enforced if the set limit of exposure is exceeded. This method requires the knowledge and understanding of what is being emitted and what dose is known to be harmless (Coglianese, 2010).
Information disclosure	This can be seen to be a popular and effective method for companies who wish to self regulate. Information can be collated and disclosed to the government and public if so desired by the company (Graham, 2002). This type of regulation has been used in different industries, potentially shaming companies into improving their performance. In the chemical industry, risk to stock prices and media scrutiny is often an incentive for good behaviour (Hamilton 2005).
Management based regulation	This is similar to performance standards and information disclosure except it allows companies to choose their own prevention strategies (Coglianese and Lazer, 2003). It is often called 'enforced self-regulation' (Bardach and Kagan, 1982) where companies are expected to comply with criteria, which allows them to reach their target. Often this is less costly and more efficient than regulations imposed by governments, which encourages companies to be more compliant. It also enables experimentation with better and more innovative solutions (Ayres and Braithwaite, 1992).

Table 7.6. Main features for ISO 10808: 2010 nanoparticle regulation.

The main features of this ISO document potentially enables company self-regulation, placing the onus on the companies working with these materials. Arguably however, if there is still a paucity of information, internal decision-making within a company may still be challenging. One of the ways forward

taken up by some European governments is to create a nanomaterial registry. This notion is discussed in the next few sections, where the objectives of a registry and the monitoring of nanosubstances are examined.

7.3.6. Registries

Facing a growing challenge of questions being raised about the safety and risk aspects posed by nanomaterials, and coupled with a lack of specific regulation, some governments have decided to try to understand the difference between bulk scale and nanomaterials. This 'evidence' based approach, would form the basis of regulation and legislation. Countries such as France, Belgium and Denmark decided that in an interim period, while there was still a paucity of evidence, and dispute over findings, a way forward should include identifying and recording the import and use of all materials in the nano form.

In January 2013, France became the first European country to necessitate the identification of the use of *'substances with nanoparticle status'* by manufacturers that *'import, formulate, produce and distribute'* as required by Articles L. 523–1 to L.523-5 of the Environmental Code (www.r-nano.fr, 2014), with the ability to register a declaration online at the website www.r-nano.fr. The rationale cited by the French government was on the basis that a registry was essential due to the lack of knowledge surrounding the execution of nanomaterials into the marketplace. Belgium and Denmark have followed suit each with their own registry with the purpose of establishing a record of products, articles and mixtures containing nanomaterials that are for sale to the general public. From the French registry alone there have been one thousand three hundred and seventeen consumer products containing nanomaterials registered on 'The Project on Emerging Nanotechnology Data Base'. Arguably however these products are only the 'tip of the iceberg', with concerns being raised by NGOs, regulatory agencies and other organisations about the many more products not currently registered. Again and to re-iterate, these uncertainties are inherent in new technologies but are arguably more so in nanotechnologies (CNBSS, 2014).

The French government has made it a necessary requirement that any company on French territory must register so that improved knowledge of worker exposure to nanoparticles can be documented. Information concerning the substance such as usage, quantities used, a noting of the sector (where the substance is used), quantity, shape and size of the nanoparticle must also be recorded. This will allow for a more accurate and *'adequate toxicity data'* for any workers that are exposed to '*substances with a nanoparticle status*' (CNBSS, 2014: WP). It is hoped that this registry will become the first step to understanding worker exposure to nanoparticles, through realising the risks and developing an appropriate regulatory scheme.

Within a registry comes a requirement to examine the way that nanomaterials are classified and engage with the issue of parity between substances when they are registered. The French registry (CBNSS, 2014: WP) states that nanoscale substances are:

> *'Defined in the Article 3 of the Regulation (EC) no. 1907/2007 manufactured intentionally at the nanoscale, containing particles in an unbound state or as an aggregate or as an agglomerate and where, a minimal proportion of the particles, in the number size distribution, one or more external dimensions is in the size range 1nm – 100nm.'*

Importantly, in specific cases and where warranted by concerns for the environment, health, safety or competitiveness, the minimal number size distribution threshold maybe reduced. While reducing certainty in some ways, this approach creates an opportunity for greater reflexivity. An example of this can be seen by the definition of fullerenes, graphene flakes and SWCNTs with one or more external dimensions below 1 nm, which should be considered as a substance with nanoparticle status according to this registry.

7.3.6.1. The Objectives of a Registry

There are multiple drivers for governments to implement registries and for organisations to use them, with some of these aspects being considered in this section. Looking at the three governments of Belgium, France, and Denmark, all three have set out a decree for mandatory reporting, based on the French system. In essence, all three systems are roughly comparable, with a high similarity. The objectives of the French decree of mandatory reporting (Décret no. 2012 – 232 du 17 février 2012), are to gather information on nanomaterials including properties, applications, toxicological and eco-toxicological data as well as gaining insight into the level of production, importation and distribution into the marketplace which would ensure traceability.

The decree defines *'substance à I'état nanoparticulaire'* as manufactured substances, which display measured nanoscale phenomena that contain primary particles, aggregates or agglomerates (CNBSS, 2014). This also includes fullerenes, graphene flakes and carbon nanotubes, and is similar to that of the EU Commission in 2011 (2011/696/EU). This decree applies to nanomaterials either alone, in a mixture or inside/coating a substance. There is a requirement for an annual declaration in May each year, starting in May 2013, to be submitted to the French National Agency for Food Safety, Environment and Labour (ANSES). Importantly, the mandatory declaration must be made once 100 g of substance at the nanoscale is produced, distributed or imported during the previous year. Financial penalties will be awarded for non-compliance (safenano, 2014). Currently REACH requires registration at one tonne and this potentially suggests that France, Belgium and Denmark believe that the one tonne limit is inadequate for nanomaterials. Although the 100 g limit for registration addresses some of the concerns about REACH's one tonne limit, for a highly toxic material, 100 g may still be a relatively large amount, and raises the concern about weight being the driver for registration.

The Belgians followed the French idea of a nanomaterial registry by announcing in February 2014 that they have ratified a *'nanomaterial-reporting scheme'* requiring companies to register mixtures and substances containing

nanomaterials that are to be taken to the market place in Belgium. Under current Belgian legislation, as stated in the 'Royal Decree regarding the Placement on the Market of Substances manufactured at the Nanoscale,' nanomaterials must be registered and then evaluated to see if there is a necessity for the whole product to be registered. This decree concerning the Belgian Nanomaterial Register is published in the country's Official Journal. It promotes:

- Better protection of human health during the evolution of nanotechnology;
- Better knowledge of exposure risks;
- Traceability to gain confidence for workers and the public; and
- Collate information on a database for future reference for national and EU level (NIA, 2015: WP).

If it is 'proven' that the nanomaterial is hazardous then the scheme promotes a fast response by health authorities, which allows the relevant information concerning the toxicology to be conveyed to HSE. It is hoped that this transparency will promote trust in the technology by consumers, workers and the general public.

The date for the start of registration of substances in the Belgian Registry is January 1st 2016 and mixtures need to be registered by January 1st 2017. This has been argued as enabling the Belgian authorities to have sufficient time to assess products that contain nanomaterials, which may need to be included in the Registry 2017.

Outside of France, Belgium and Denmark, a number of countries and organisations are sponsoring nanomaterial testing. The USA for instance, through the EPA, is sponsoring an examination into the environmental effects of fullerenes, and various single/multi-walled carbon nanotubes and nanoparticles. The outcome of other OECD projects is also expected to contribute to the EPA's efforts to enhance its regulatory oversight of nanoscale materials (EPA, 2014). The EPA has taken what might be described as an active participation in the Working Party on Manufactured Nanomaterials (WPMN), which engages in an

assortment of schemes that will advance in an understanding of the potential benefits and risks of nanomaterials. They also contribute to these ventures, with the aim of helping leverage international resources and expertise, in particular the safety testing of the Representative Set of Manufactured Nanomaterials, which has the potential to fill data gaps. This suggests that the USA has an interest in contributing to regulation beyond its own national borders, with its results being included in registries in Belgium, France and Denmark. Alongside this, the USA has engaged in a voluntary registry system, the 'Nanomaterial Registry', where stakeholder information is sought to inform decision-making. The purposes of Nanoparticle Registry (2014) are shown in Table 7.7.

Number	Purpose
1	To build: A repository of curated nanomaterial information by systematically archiving data from a broad collection of publicly available nanomaterial resources
2	To deliver: Authoritative and useable information on the interactions of well – characterised nanomaterials in biological and environmental systems via a public website
3	To provide: Tools for searching and viewing data
4	To improve: The quality of nanomaterial information by driving standards of accepted procedures and reporting requirements
5	To promote: The use of a well defined minimal information about nanomaterials (MIAN) framework and of common nanomaterial standards
6	To identify: Reliable information about nanomaterials that can be used in regulatory decision making

Table 7.7. Purpose of the USA nanoparticle registry.

Pivotal to any registry is the capability of monitoring exposure to products, which is examined in the following section.

7.3.6.2. Registries to Monitor Exposure

There has been much positive discussion in favour of a registry system for a *'substance with nanoparticle status'* or those *'contained in a mixture or without being bound or material ('article') from which it is likely to be extracted or released under normal or reasonably foreseeable conditions of use'* (CNBSS, 2014: WP). This is a broad and encompassing approach that may capture many nanoparticle products.

Hansen *et al,* (2007) has given an overview of the registry concept and developed a method for dividing the nanomaterials into sub-categories. This is significant for identifying hazards to enable risk assessments to take place, where sub-categories can be classified and divided into materials containing nanoparticles, and nanoscale objects that are suspended into solids, and where the nanoscale object may break free. The category perceived as giving the most concern is that of nanoscale objects migrating into the environment, particularly for accidental splash exposure and release (Hansen *et al,* 2007). This arguably creates a necessity for accurate reporting and recording of data.

Although the French registry is monitoring the exposure of workers to nanoparticles, not consumers, it must cover the traceability of these nanoparticles in goods as this has an impact on consumer risk. This is an important point and four scenarios have been created to demonstrate this (CNBSS, 2014), as detailed in Table 7.8.

Number	Scenario
1	The nanoparticle substance is sold to a consumer. This substance could be in the form of material or mixture. When the consumer uses the substance under normal conditions, nanoparticles are released, potentially putting the consumers' health or the environment at risk.
2	The nanoparticle substance is sold to the consumer but the nanoparticles are bound inside a mixture or to a material, therefore rendering the substance *'safe'* under normal conditions. Abnormal usage has the potential to create risks to the environment if these substances are not recycled appropriately.
3	The substance containing nanoparticles is sold to the consumer as a mixture or material where the nanoparticles are bound within them. Traceability of the substance throughout the full length of the chain of production is necessary to maintain a lower risk to the consumer.
4	The nanoparticle substance is consumed during the production process therefore any potential threat from nanoparticles is negated. However, this needs to be a controlled consumption to avoid any of the nanoscale – waste material being released into the environment. Consumers' risk potential is limited although it is necessary to make sure that all the substance has been consumed during the production process.

Table 7.8. Scenarios registries may monitor.

Arguably with the use of registries, moderate traceability of nanomaterials can be documented. The four possible scenarios in table 7.8 created as examples, demonstrate the difficulty of accuracy without the availability of machinery able to record and take precise measurements of nanomaterials.

7.4. Insights from Different Sectors

While multiple approaches have been used to engage with nanotechnology through regulation, albeit often not directly, this section aims to pull together insights from different sectors currently engaging with nanotechnology products. Critical to the discourses regarding nanotechnology regulation is the potential not only to regulate products through stakeholders, but also how products should be

labelled (USDA, 2003: WP). Not only is this a consumer protection issue, but also in principal it acts to reduce consumer fears, which have been detrimental to other high technology products (Porter, 2012). Drawing on three distinct areas of nano foods, cosmetics and nanomedicine, current strategies for regulating nanoparticle products are examined in the following three sub-sections.

7.4.1. Regulating Nano Foods

Different approaches to nanomaterials have been taken throughout different sectors and related to different product applications. For example, nanotechnology related to food is at present regulated under general food production systems (Brazell, 2012). While the debates continue, the only real move towards specific regulation has been through an amendment to Legislation 1169/2011, where all nanoscale substances must be listed in the ingredients followed in brackets by the word 'nano' (Bergeson, 2013). The amendment defined nanomaterials as:

> *'Any intentionally manufactured material, containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm to 100 nm'.*

Considering this definition, it is clear that there may be profound differences between products based on sizes and percentages of products in all three physical dimensions. In practicality, this may result in substantial differences in health and safety, as well as potential benefits from any product.

Examining the arena of nanotechnology foods, the European Food Safety Authority (EFSA) has been active in the EU, examining the need for nanotechnology specific regulation. It is fair to say that the EFSA is concerned about its responsibilities regarding nanoparticles due to uncertainties surrounding scientific opinion (EFSA, 2008). It published a Scientific Statement in 2008 on the safety of silver nanoparticles as an application had been made to include

silver hydrosols as an approved substance for food supplements (Porter, 2012). EFSA declared in the Statement that there is insufficient evidence on the safety of silver nanoparticles to use them in food substances. In what appears to be an approach in line with the precautionary principle, the EFSA claimed substantive knowledge gaps that would create unknowable risks.

In 2008, The European Commission proposed a rewrite of the Novel Foods Legislation to include new technologies. This was explicitly for nanotechnologies and in 2009; the proposal was endorsed by the European Parliament who urged the introduction of mandatory labelling to list ingredients and also proposed the inclusion of a definition of nanoparticles (Porter, 2012). Other proposals by the European Commission included nanomaterial specific requirements for testing such as 'non-animal' test methods. Foods produced by using nanotechnology or that contain nanomaterials must be assessed and then authorised before sale. This could have created problems for the commercialisation of foods containing nanoparticles but the European Council decided that the revised Regulation (June 2009) would not make the authorisation of these foods conditional upon test methodologies being developed (Porter, 2012).

To address this issue in regard to nano-foods, the EU has moved to update its current regulations in regard to food additives. This appears to be based on the European Parliament's Committee on Environment, Public Health and Food Safety, which has recently stated that nanotechnology products should have a separate lower limit value to those of the bulk forms (Halliday, 2007). To date this change is still being discussed, with no changes to the regulation at this time. Even though it is still in the discussion stage, it is suggestive of a moving perception that bulk material physicality cannot be regarded as the same as at the nanoscale.

There is a requirement that all new food products and ingredients need to have received pre-market approval by the EU Novel Foods Regulation. To partially encompass changes to the food landscape by nanotechnology, the European Commission has proposed a revision (CEC, 2008b) to define novel foods to

include any foods that have been modified by new production processes such as nanoscience or nanotechnology that potentially could impact on the food. This revision requires that an application to the European Commission must be made to authorise a novel food to be used as an ingredient so that the European Food Safety Authority (EFSA) can evaluate whether the food is dangerous to consumers. An assessment must be made on the intended use of the food and an examination of the nutritional content and composition as well as any chemical and microbiological contaminants. Other studies are also required such as allergenicity (whether a substance causes an allergy) and toxicology as well as any details of the manufacturing process (Hansen, 2009). While attempting to 'improve' the landscape of commercial nano-food, there are still issues that need to be addressed. In particular, this revision does not make any distinction regarding nanoparticle size, enabling nanomaterials, which have a bulk scale counterpart to not sit outside of new safety assessments, as long as the substance has been approved in its bulk state (Hansen, 2009). The EFSA have concluded that when risk assessment guidance recommends that the special properties of nanoparticles should be considered, a review will take place (EFSA, 2008). While, there is still much offered potential scientific and health benefits offered by nano-foods, there is clearly much to draw out for the best way forward for packaging and labelling nano-foods.

Moving on from examining nanotechnology food based regulation; the next section examines another major sector of cosmetics, in cosmetics regulation.

7.4.2. Regulating Cosmetics

Nanotechnology has attracted much attention from the cosmetics sector, but has also generated attention from regulators for how to engage with this physical phenomenon. The Cosmetics Directive (1976) (76/768/EEC) is the basis of EU cosmetic regulation, which is made up of over fifty amendments that have been added over the past thirty years. With advancements in technology and in particular nanotechnology and perceived legal uncertainties (Porter, 2012), the EU revised the Directive into a new Regulation (EC No 1223/2009, EU 2009c)

that took effect in 2013. This shift, mentioned nanomaterials directly in the Cosmetic Regulation (EU, 2009c) stating that they are to be limited to biopersistent and intentionally manufactured (engineered) materials. The revision of the cosmetics regulatory regime was a defining moment for nanotechnology as cosmetic nanomaterials were addressed explicitly for the first time (Brazell, 2012).

Before updating the Cosmetics Directive, Annex II set out a list of prohibited substances and Annex III set out those substances that may be used in certain conditions or with restrictions, although there was no reference to particle size. This meant that the Old Cosmetics Directive did not restrict nanoscale substances judging them to be the same (therefore safe) as their bulk counterparts (Brazell, 2012). The Old Cosmetics Directive does make reference to health and safety by not allowing products that may cause harm to human health to be allowed on to the market in the EU (Article 2, Old Cosmetics Directive, 1976, Brazell, 2012). The manufacturer must keep a dossier to hand over to the authorities of the Member States if required. This has to include the microbiological and physico-chemical specifications of not only the finished product but also the raw materials including an assessment of how the product may impact on human health (Article 7a, Old Cosmetics Directive, 1976, Brazell, 2012). The Scientific Committee for Consumer Products (SCCP) have published '*Notes for Guidance'* to cover health and safety issues such as: *'oral toxicity, mucous membrane irritation, skin absorption, reproductive toxicity, inhalation toxicity, and phototoxicity and photomutagenicity'* (Brazell, 2012: 174).

Article 13 of the New Cosmetic Regulation requires specific information to be submitted to the Commission about each cosmetic product before commercialisation, which includes disclosure of, *'the presence of substances in the form of nanomaterials'*. For products containing nanomaterials in accordance with Article 16, the Commission must be informed six months prior to a product being placed on the market if it contains nanomaterials. Specifically, six criteria must be met, as detailed in Table 7.9.

Number	Criteria
1	Identification of the nanomaterial.
2	Chemical properties.
3	Particle and physical size.
4	An estimation of the amount of nanomaterial in the product.
5	A toxicological profile of the nanomaterial.
6	Any foreseeable exposure level of the product.

Table 7.9. Article 16 for nanomaterial containing cosmetic products.

As has been mentioned for other regulatory aspects in this study, there is still an issue for any criteria requiring an understanding of the underlying science of nanotechnology products.

Importantly, cosmetics manufacturers are required to assess the safety of any product they wish to market under the 1976 Cosmetic Directive by considering, *'the general toxicological profile of the ingredients, their chemical structure and their level of exposure'* (Chilcott and Price, 2008: 320). The Competent Authorities in Member States must also be notified when manufacturers are placing a product on the market.

The Scientific Committee on Consumer Safety (SCCS) can provide an opinion on a nanomaterial if the Commission has concerns over its safety. A report by the SCCS must be made within six months and any extra data that is required must be provided. The Commission must also catalogue any nanomaterial placed on the market that is contained in a cosmetic product and report it to the European Parliament and Council on a yearly basis to demonstrate the increasing use of nanomaterials in cosmetics (Porter, 2012).

Both the raw materials and the finished cosmetic products come under the EU Cosmetic Directive EC 76/768/EEC and EC 1223/2009 and REACH EC 1907/2006 and CLP (Classification, Labelling and Packaging) Regulation – EC 1272/2008. Any non–EU importers/exporters of finished cosmetics or cosmetic

ingredients must comply with these regulations before their cosmetic products are placed on the market (CIRS, 2013).

Under REACH, there are some exemptions for cosmetic products. These relate to human health exposure hazards but other risks, such as environmental hazards from bioaccumulation, have the potential for a cosmetic product to fall under the assessment scheme of REACH (Brazell, 2012). Any information not covered by REACH that is required, is collated by questionnaire by the formulator and passed to the supplier, allowing any necessary information needed for regulatory compliance or perhaps to defend any liability claim. The regulation for the safety of cosmetic products is regulated under the Product Safety Directive (Brazell, 2012).

In 2007, the SCCP taking into consideration the suggestions in the report *Nanoscience and Nanotechnologies: opportunities and uncertainties,* June 2004 from the Royal Society concluded that nanoparticles should be treated as new chemicals instead of their bulk counterparts, from the aspect of risk from skin absorption in healthy or diseased skin (SCCP, 1147/07, 2007). They also addressed the question as to whether the *Notes for Guidance* needed to be revised in respect of nanoscale titanium dioxide and zinc oxide. Brazell (2012: 177) has argued that *'for the foreseeable future each safety dossier concerning nanomaterials needs to be evaluated on a case–by– case basis.'*

Article 13 of the new Cosmetics Regulation states that the producer of each cosmetic product must give specific information such as: category, name, country of origin, any nanomaterials present, and the framework for the formulation, before being placed on the market (Article 13, 1223/2009). The person that places the cosmetic product in the EU market has the responsibility of keeping the product traceable throughout the supply chain.

Article 16 of the new Cosmetics Regulation covers the new requirements for cosmetic products containing nanomaterials. Its priority is to require the product to be safe, stipulating that human health must be ensured. This notification must include: amount of nanoparticles contained in the product, size of particles, identification of the nanoparticles plus its chemical name, safety data and

toxicological profile, and any foreseeable risk or exposure hazards. If there is insufficient safety data, the SCCP may request that the nanoparticle be prohibited and placed in Annex II. Any materials placed in Annex III can be used but are subject to restrictions, which is to prevent any potential health risks from the nanomaterial. Labelling has also received attention with Article 19 (1) (g) stipulating that nanomaterials must be labelled *'nano'* and included in the list of ingredients. An example of this would be zinc oxide *'nano.'*

In 2014, the European Commission placed a catalogue on the market to be made publicly available and regularly updated, for all nanomaterials that are currently used in cosmetic products (Article 16 (10) (a): 2009). The aim is for all possible and foreseeable risks and exposure conditions to be included. An annual status report must be submitted to the European Parliament and Council that will include updates on safety assessments and guides, plus any information on international cooperation programmes (Brazell, 2012).

Article 20 states that by July 2016, the European Commission must draft a report on the subject of advertising claims made by cosmetics containing nanoparticles. Advertisements must not be allowed to mislead the consumer into believing that a cosmetic product has functions or characteristics that it does not. Therefore Article 20 (1) prohibits the use of trademarks, pictures, names, texts, or other signs on the labelling that may deceive the consumer. Also 'nano' must not be used to signify nanomaterials are being used when there are no nanomaterials contained in the product.

The adaptive process of requiring new information is expected to continue, with a new review being due to take place to amend the whole regime where necessary in 2018. This will take into account any new information on health and safety and look at any scientific progress that has been made (Article 16 (11): 2009). This approach is clearly seeking to build information about these products and to inform the consumer, on the basis of these products containing nanomaterials constituents.

Stepping beyond cosmetics, the next section explores pharmaceuticals and nanomedicine.

7.4.3. Regulating Nanomedicine

The pharmaceuticals sector is regarded as highly regulated (Brazell, 2012), particularly for safety, efficacy and quality (Mann and Andrews, 2014). Arguably, pharmaceutical products must abide by a relatively higher standard of regulations than the previously mentioned products in the last two sections. Alongside this is the need of government approval through regulatory bodies (Abraham and Lewis, 2002) for medicinal products, with information required for the product physicality, uses, labelling and packaging before it is marketed (Mann and Andrews, 2014). It is also a requirement of the pharmaceutical companies to track the effects of the product on the consumer and to report any unfavourable effects through pharmacovigilance (Brazell, 2012).

Medicinal products in the EU are regulated through a variety of regulations depending on the perceived risk of the drug, and how much information is currently available already on its physicality (Jackson, 2012). There is specific regulation for medicinal items used for blood products, products for paediatric use, herbal products used for medicinal purposes, and orphan drugs. A set of community guidelines; *'The rules governing medicinal products in the European Union'* have been published to support this legislation, which includes both scientific and regulatory guidelines (ec.europa.eu, 2012: WP).

Currently, the regulatory framework does not contain any specific requirements for nanoparticles. In 2006, the European Medicines Agency (EMA) published several 'Reflection Papers' that included general nanomedicine - EMA, 2006, iron nanoparticle based products - EMA, 2011a, and liposomes - EMA 2011b (ema.europa.eu: 2011). An 'Expert Group on Nanomedicines' has been set up by the EMA to give support to the Agency with guidelines to nanomedicines, specialist scientific knowledge and the Agencies' activities (ema.europa.eu: 2011).

When constructing legislation for nanomaterial products it is important to carry out a careful risk management and risk assessment on a case-by-case basis before any product can go to market. A significant point to remember is that medicines containing nanoparticles have potential risks attached that are still unknown, therefore the EMA requires a complete and thorough evaluation that must be recorded and the information held in registration dossiers (Bleeker *et al,* 2012).

Article 11.3 (b) and 19.2 (b) of REACH states that all medicinal products marketed in the EU must have marketing authorisation (MA). A medicinal product is defined as a substance or a mixture of substances to be used to prevent or treat disease, or be dispensed to aid medical diagnosis or to restore, correct or modify physiological human functions. It may also include micro – organisms such as vaccines as well as natural occurring plant extracts. All of these products must be authorised by a governmental body recognised by REACH or the EU agency (Brazell, 2012). For any product to have MA, its safety must be proven alongside its quality and efficacy. This involves rigorous pre-clinical testing and clinical testing, carried out by EU procedures to reach EU standards. All data supplied must demonstrate control, stability, and characterisation of the product to prove its quality (Article 6 Directive 2001/83/EC).

Importantly, many medicinal products that contain nanoparticles have been on the market for several years, often to aid in drug delivery (Brazell, 2012). A term that has arisen in this area is nanopharmaceuticals (this includes nanoparticle and liposome drug delivery systems) the 'payload' is key rather than the actual system of delivery. Many of these systems have already got approval under existing regulations (Brazell, 2012), which is due to the processes being argued as being well understood. However, the system of delivery can have numerous effects including the positive and negative. The positive effect is the potential for the nanoparticles to have an affinity for tumours aiding in the direct treatment of cancers but the negative aspect could potentially cause immunological effects such as surface modifications that are not shown by the bulk form (Brazell, 2012). This poses the question as to whether nanopharmaceuticals should be treated as separate entities and require new authorisation as the bulk form of the chemical has already been authorised? There is also the potential for

nanopharmaceuticals to reach tissues and cells that larger pharmaceuticals may not and the possibility for novel effects to also take place, but is coupled with a risk that these nanomaterials may create different pathways throughout the body. One of the biggest challenges facing the creation of nanomaterial legislation in the pharmaceutical sector is the difference in their stipulative definition by different stakeholders. EMA's Committee on Medicinal Products for Human Use (CHMP) states that '*in the pharmaceutical sector'* the definition: *'should not prejudice the use of the term 'nano' when defining certain pharmaceuticals and medical devices'* (Bleeker *et al,* 2012: WP). EMA produced a 2006 Reflection Paper (EMEA, 2006) that sets out the definition of the nanoscale as being from 0.2 nm at the atomic level to approximately100 nm (ema.europa.eu: 2006). Yet on their website they claim that the upper limit is 1,000 nm instead of 100 nm, creating further confusion. EMA also consider liposomes, with particle sizes over 100 nm to be nanomedicines and take the lower limit to be 0.2 nm instead of 0.1 nm as the EC definition states (EMEA, 2006). Unfortunately, these unclear statements create further opacity and in many ways obligate stakeholders to develop an in depth understanding of the underlying science.

The UK's Medicines and Healthcare Products Regulatory Agency (MHRA) Commission on Human Medicines in 2006 carried out a survey looking at all the nanoparticle studies and literature relating to healthcare and nanomaterials (mhra, 2006). They concluded that the chemical toxicity of bulk materials should not be an indication of the toxicity of materials at the nanoscale. They also indicated that previous nanotoxicology reviews on nanomaterials contained in health care products is limited and possibly irrelevant, observing that the safety data obtained on particles at the nanoscale with diameters between 100 – 1000 nm (including the majority of drug delivery vehicles) does not always transfer directly to particles of 1 – 100 nm diameter (mhra, 2006).

When examining medical devices, (products that include those that may be used inside the body or in surgery, such as nanoprobes, nanostructured scaffolds used for tissue replacements, and implantable nanoelectric systems) the EC New and Emerging Technologies Working Group (N&ETWG, 2007) concluded that

nanoscale products should be treated as a high-risk group. They (N&ETWG, 2007: 6) stated that:

> '*All devices incorporating or consisting of particles, components or devices at the nanoscale are in Class III unless they are encapsulated or bound in such a manner that they cannot be released to the patient's organs, tissues, cells or molecules.*'

It was also recommended by the Working Group that regulatory guidance for stakeholders should be developed, due to the many unknown risks surrounding nanotechnology. Currently, a document is being prepared - *'A Meddev guidance document'* to deal with medical devices that contain nanoparticles plus the creation of a 'working group' to help with the development of standards under the International Organisation for Standardisation (ISO/TC194/WG17) to evaluate the biological impact of medical devices that contain nanoparticles (isotc, 2012). A revised regulation is currently being developed to make provisions for medical devices that contain nanomaterials (ec.europa.eu, 2012: WP).

The N&ETWG's 2007 report (N&ETWG, 2007: WP) also did not give a precise definition of *'nano'* but states that *'There is no scientifically based cut – off point to define nanoscale. The size below which nanomaterials can display specific properties varies for different materials*' (ec.europa.eu, 2012: WP). Amendments may be necessary to the Commission's Recommendation should nanomaterials need specific requirements.

After much consideration of the national and EU regulations, the major themes are pulled together in the following summary.

7.5. Summary

This chapter has examined UK and EU based regulations for how they interact with high technology products, and in particular nanotechnology and

nanoparticle products. Consideration has been made of various regulatory systems such as REACH, ISO, COSHH and registries, and while arguing that they all have something to offer nanoparticle regulation, there is still much to be done if any of these systems are to effectively be of use to safeguard against societal and environmental harm from nanotechnology. It is of course recognised that there is a balancing act between safeguarding and promoting commercial activities and product innovation that can enhance the economy and societal health for example. Having taken a bricolage approach to numerous sectors and regulatory instruments, there are clear emergent themes, with the most pivotal being a lack of scientific data. This aspect has been addressed in previous chapters also, but arguably, the greatest foreseeable barrier to regulation is the unknown physicality of nanoparticle products, which have received at best limited scientific attention outside of R&D testing. Thus, without a greater scientific focus being made towards the actuality of these products it is difficult to see a way forward for fit-for-purpose regulation. More than this, with the EFSA implementing the precautionary principle for nanomaterials food additives, due to a paucity of data, there is some urgency in addressing this.

Overviewing the most prominent and noteworthy discourses regarding nanotechnology regulation, there is a very real possibility that nanotechnology products are being commercialised without adequate safety testing to elucidate mitigation measures. On this basis, and as discussed within this chapter, the notion of case-by-case testing for these products is suggested, depending on currently held data, product application and sector.

To draw this study to a close, the following chapter on discussion and conclusions will take a broad overview of research findings, while making suggestions for how regulation might be used for nanotechnology and nanoparticle products.

Chapter 8. Discussion and Conclusions

8.1. Introduction

Nanotechnology is a pervasive collection of high technology products that has become a 'buzz word' over the past decade mixing scientific reality and speculative persuasive marketing claims. Within this zeitgeist, thousands of products are currently being sold in the global market place containing nanomaterials. Due to their enhanced properties, they have received much commercial interest, but with limited attempts to produce nanotechnology and nanoparticle specific regulation. Although the difference between nanoscale and bulk materials is readily acknowledged in scientific arenas, from a regulatory perspective, law has been slow to acknowledge this difference in a meaningful way, and has predominantly relied on current bulk scale regulations instead of implementing specific nano-based regulations. This has at some level been beneficial to product manufacturers facilitating quicker routes to market in line with neo-liberalist frameworks.

This study has examined numerous aspects of the journey of nanoparticle products from inception through to disposal, via a bricolage approach to better understand how nanoparticles 'should' be regulated to ensure that commercial innovation is encouraged, while risks are mitigated. This has led to several main themes being explored, including neo-liberal technology frameworks, what nanoparticles are from a discursive and physical perspective, how these products are used commercially, their perceived risks and benefits as well as how to insure such products. This has been alongside health, safety and environmental implications, leading to current regulatory approaches and discourses being used to frame the nanotechnology and nanoparticle regulatory challenge. As such this chapter seeks to provide 'answers' to these 'questions', by providing a study overview, engaging in a discussion of key themes, drawing conclusions, making recommendations based on research findings, suggesting future work, and recognising research limitations. As a starting point, the following section

examines the purpose of this study, to provide a research overview and contextualise all other chapter sections.

8.2. The Purpose of This Study

Many articles from a variety of disciplines have considered the potential challenges posed by nanotechnology and in particular nanoparticle products to the current regulatory landscape. This study set out to address the question derived from my emic sensitisation and etic grounding within the extant literature of, 'how should nanoparticles be regulated so that risk is minimised while business innovation and commercialisation is encouraged?' This approach has recognised that regulation is a balancing act between these and many other drivers, and that any suggested change is unlikely to provide the 'right' answer. Problematically, what is right for one stakeholder may well be wrong for another. Thus, this study sought to encompass the notion that regulation is culturally embedded within particular timeframes, where through time, regulatory drivers can change. Following on from this thought, in this study regulation is considered as evolving and adaptive, where change is a 'natural' part of the process.

Through this study, my aim was to elucidate regulatory issues and structures that are relevant to nanotechnology and nanoparticles. This led to several research questions which have been specifically addressed in this study, that have firmly sought to ground this study within a need to engage with nanoparticles constructed as physical entities to better regulate their commercial promises but limit their risks. Taking this view meant that an overview of nanoparticles was carried out from inception through to manufacture, usage and disposal. This approach is novel and coupled with the previously mentioned factors has answered questions regarding how to regulate nanoparticles, but also importantly, raised new questions, based on this study.

Moving into this chapter further for the discussion and conclusions drawn, the next section provides a brief research overview.

8.3. Research Overview

Overviewing the extant literature showed that although there has been much debate regarding nanotechnology and nanoparticle products, there was still much to unpick. This study undertook the selected targeting of research areas discussed in the last section, with this section providing a brief review of extant literature, to again remind the reader.

Targeting what is arguably the greatest macro-scale deficiency within extant literature is the lack of direct discourse and recommendations for how nanoparticles should be regulated to minimise risk while encouraging innovative commercialisation. Although addressed in other high technology arenas, such as biotechnology and pharmaceuticals (Fraser, Daubert, and Van der Werf, 2011), there is often little discourse regarding the neo-liberalist influence on high technology regulation, such as nanotechnology. A lack of examination on this aspect has in general resulted in a failure for nanotechnology discourses to consider the functional foundational physicalities affecting nanotechnology regulation.

Prior studies have predominantly constructed nanotechnology as just smaller products than their bulk counterparts, missing much of the nuance of nanoparticles, which I argue is critical for their regulation. This has been alongside little consideration of the potential influence and impact of wider socio-linguistic constructions of nanotechnology (Fadeel and Bennett, 2010). Pivotally, and while many areas outside of legal regulatory discourses have discussed aspects such as nano, nanotechnology and nanoparticle definitions (Delgado, 2010), attention paid through a regulatory lens has been limited. While I caution against concretising definitions, they are helpful demarcation points for working with complex, opaque and easily misunderstood high technology products (Harris, 2007).

Within many disciplines examining nanotechnology and nanoparticles, are discussions about the use of these technologies. Unfortunately this has often been through ‘good’ or ‘bad’ stories, which overly simplify the phenomenon of

nanotechnology (Marchant *et al*, 2008). While helpful for aiding sense being made, much critical information can be missed out through this process. More than this though, these simplified factors, have often led to simple perceptions of how to regulate, but at the expense of poorly constructing the physical reality of these products.

There has been much debate about the risk element of nanotechnology and nanoparticle products, particularly when positioned through bad stories (Poland *et al*, 2008). This has resulted in what I consider an overly pessimistic narrative of nanoparticle technologies, and with very little examination of how insurance is linked to risk for these products (Baxter, 2008).

Receiving much critical attention in both scientific and legal literature is the examination of health, safety and environmental implications of nanoparticle products. While much scientific literature has focussed on demonstrating the potential damage to people and the environment from nanoparticles, studies have in essence been limited in scope to more 'laboratory' focussed areas, with much still to be elucidated from practical use and exposure (Binion, 2008). More than this though, as nanoparticles can easily change their size and shape in the 'real' world (Binion, 2008), it is questionable at what level testing is of practical use in its current form. It is recognised that there is a severe paucity of usable data to better help understand the physical aspects of nanoparticles, as well as nanotechnology. While it might appear that this is an insurmountable challenge, as mentioned previously, other sectors such as biotechnology and pharmaceuticals have much more actively engaged with the regulatory system to highlight challenges, and ways to deal with them.

Finally, and summing up all of the previously discussed aspects in this section, is the need to synthesise all of these often conflicting discourses into an intelligible way forward for nanoparticle regulation. Reiterating the previous stance, that crippling commercial innovation through 'heavy' regulation will most likely be regarded as unworkable, as will mitigating 'all' risk, a practical and pragmatic approach from the extant literature and my sector sensitisation is needed, and discussed throughout this chapter.

The following section goes on to explore the themes considered in this section, while linking them to specific research questions for reader clarity.

8.4. Discussion – Key Findings

Taking a broad overview of this study, this section discusses the key contributions to the knowledge base, and addresses the questions derived from my emic sensitisation and etic contextualisation against extant literature.

Due to the pivotal nature of the main research question driving this study of 'how should nanoparticles be regulated so that risk is minimised while business innovation and commercialisation is encouraged?' this is answered in Section 8.6, drawing on findings from this and other sections. Looking at the other research questions, the key findings are as follows:

2. How are high technology products regulated, and how does the neo-liberal regulatory framework influence this?

Neo-liberal regulation 'suggests' the commercialisation of innovative technologies as beneficial in several ways with variations, depending on the sector that products are sold into. This can include social, economic, and medical benefits, and for example, the commercialisation of a nanoparticle product that can act as a therapeutic to reduce disease states, while increasing/maintaining employment and generating taxable revenue etc. Many scholarly works have addressed neo-liberalist under pinnings for high technology regulation (Abraham and Lewis, 2002; Davis and Abraham, 2013), where a stance is roughly taken that a 'priority' is the commercialisation of innovative products. Nanotechnology and nanoparticles have predominantly sat outside of this argument (often not being specifically cited), but yet at the same time, still exist within it, as a collection of high technology products. As such, commercial exploitation has been a core concern (even if the reason why was not fully understood), resulting in rapid and mass commercialisation of nanotechnology and nanoparticle

products. This has led in other more established sectors to arguments based on commercialisation first, and risk mitigation second (Fisher, 2009), and while not necessarily capturing the nuance of neo-liberalist arguments, it does show how commercial activity is a prime concern.

3. What are nanotechnology and the product class of nanoparticles, from a scientific and socio-linguistic perspective?

From a physical and scientific perspective nanoparticles are a 'separate' product class from forerunner technologies such as micro-particles, and bulk scale materials (El-Shall and Edelstein, 1996). Nanoparticle physical action is often based on different physical mechanisms for their action with the physical world, meaning that the benefits of being nanoscale also necessitates a regulatory view that they are 'different' (Eastoe, Hollamby and Hudson, 2006). Importantly, this means that their risks cannot be assumed to be identical to larger scale products, and previous classifications of material and product safety, are largely unknown. This is a critical point for this study, and I argue obligates a stronger regulatory view that these products cannot be regarded as the same, unless demonstrated to be so through scientific testing. Finally, there is often confusion arrived at by interactions with socio-linguistic constructions of nanotechnology and nanoparticles (Boholm and Boholm, 2012), and as they are unhelpful should be avoided, and scientific definitions and language based constructions given a prime position.

4. How are nanotechnology and nanoproducts used commercially, and what are the perceived negative and positive attributes potentially influencing their regulation?

As mentioned throughout this study, there are numerous commercial products currently based on or containing nanoparticles, which are sold in 'all' sectors (CPI, 2014). The word 'all' is used, as it is difficult to find a sector without nanoparticles used somewhere, but of course, no definitive claim is being used to this literally being the case. With so many products being sold into many different sectors, this raises a variety of challenges, and discourses arising from

different stakeholders, for and against their use. As a foundation, I worked on the basis that discourse is not a neutral medium (Rorty, 2009) whereby the potential power of discourses must be considered for being able to influence how stakeholders make sense of nanoparticles and wish to regulate nanoparticle products (Weick, 1995). Drawing on these aspects and against a pervasive product usage, I argue that it is too simple a notion to suggest that nanoparticles can be regulated as 'nanoparticles', or in other words as a single product class. Their usage in multiple sectors, with different applications and target users, suggests that nanoparticles should be regulated on a case-by-case basis, albeit potentially within demarcatable frameworks and reference points. More about this will be discussed in Section 8.6.

5. How are nanoparticle products perceived from a risk perspective, and how does this influence their insurance?

Against a backdrop of good and bad stories, there is much concern within extant literature about the potential risks for nanoparticles (Baxter, 2008) also 'bleeding' into insurance discourses. At present, there is limited and often no provision for specific risk assessments of nanoparticle products, which is also echoed in other nanotechnology literature (Dana, 2012). This is highly problematic for risk and insurance-based decision-making, where a lack of information often means that 'we don't know what we don't know'. Compounding this difficult task is a lack of 'real world' data from scientific testing to validate assumptions and claims being made about nanoparticle product risks (Yon and Lead, 2008). In practical terms, this ultimately leaves many businesses, consumers and insurers with a difficult choice for how to proceed, within the two formers cases is whether to use or consume a product, or in the latter whether to insure (Baxter, 2008). Without fit-for-purpose testing to validate claims and discourses, it is unlikely that clarity in this area can be made.

6. What are the health, safety and environmental implications of nanoparticle products, and how might regulation be used to address this issue?

Following on from the prior question, there are many concerns about the health, safety and environmental implications from nanoparticle products (Boucher, 2008; WHO, 2008). While much has been said about this issue, in practical terms, very little has been carried out and achieved. Arguments are continually made about the danger of nanoparticle products, but little testing has been carried out, meaning that much information is still needed (Yon and Lead, 2008). More simply, an immediate focus must be made on linking claims with scientific data, as with the exemplar of CNTs being similar to asbestos for instance, health drivers are there for such data to be elucidated (Poland *et al,* 2008). Due to the variability of nanoparticles in different sectors with different applications, being used, and disposed of, this suggests in depth testing programmes to determine product safeties in multiple stages of the product's life. It would seem practicable to implement a system similar to Pharmacovigilence (Mann and Andrews, 2014), whereby in certain sectors, required post-manufacture testing is carried out, and data collected.

7. What are the regulatory approaches to nanotechnology and nanoparticles that might best result in regulation promoting innovative commercialisation while addressing needs to mitigate risk?

This question and theme is considered in Section 8.6, due to the similarity with the overall main question driving this study.

8.5. Conclusions of the Study

This study has examined numerous aspects related to the regulation of nanoparticle products, with this section drawing the conclusions together. As part of this process and examined in this section are five major themes, including (1) the isthmus between science and law, (2) the complexity and opacity of nanotechnology, (3) paucity of data, (4) defining nanotechnology and nanoparticles, and finally, (5) regulating nanotechnology. Importantly, these sections are examined separately in the following sections, which enable

regulatory recommendations to be made, as well as suggestions for future work and study limitations in later sections in this chapter.

8.5.1. The Isthmus between Science and Law.

Nanotechnology is a pervasive collection of products that physically exist in 'all' sectors, with the number of products being commercialised growing year-on-year (Bowman, 2010). As well as having a physical presence, nanotechnology also exists in the social and legal world, where it is re-contextualised by individuals with different knowledge (i.e. scientists and legal actors). This has created challenges for the way that nanotechnology is engaged with, and scientifically and legally constructed through language (Macoubrie, 2005). Simply, scientists have predominantly framed nanotechnology as physical phenomena, with little consideration of the social and legal aspects for the implications of nanotechnology R&D, manufacture and commercialisation. Law however has had greater difficulties in engaging with the physicality of nanotechnology, with many legal actors not having the prerequisite knowledge to adequately engage with the physicality of these phenomena, and following social and legal structures (McHale, 2008).

8.5.2. The Complexity and Opacity of Nanotechnology

This study has focussed on nanoparticles as they are seen as the vanguard of nanotechnology R&D and commercialisation. As a product class nanoparticles have pervaded 'all' sectors, being used in a myriad of manufacturing and consumer-based applications. Nanoparticles are however a collection of highly complex and opaque physical entities, which often display unique properties distinct and unique from their bulk counterparts (Cientifica, 2003). While these properties make them desirable for commercial applications, understanding the physical aspects of the physical properties has been no small challenge for the natural sciences, with much still to learn (Munshi *et al*, 2007). Importantly, and even though the greatest volume of discourse has been driven by the natural

sciences, other disciplines such as law have had much to say about nanotechnology. At best discourse has 'adequately' captured the physical phenomena of nanotechnology, and at worst, which has frequently been the case, it has misconstructed the physical phenomena. This has created a challenge for legal actors, often without the 'prerequisite' knowledge of natural science-based discourse, leaving legal actors trying to circumnavigate a sea of 'good' and 'bad' discourse (Beard and Easingwood, 1996). In turn this has created challenges for creating shared meaning for the physicality of nanoparticles and in the use of language for nanoparticles, which has often not been fit-for-purpose.

8.5.3. Paucity of Data

A lack of systematic scientific testing and research into the physical aspects of nanoparticles has created a paucity of information, for their physical characteristics and how they interact with biological systems (Yon and Lead, 2008). The small size of nanoparticles means that they have a potential to interact with biological systems in ways that prior technologies have not managed, and for example, being able to pass through the blood-brain-barrier in humans (Jain *et al*, 2012). The increased ability for nanoparticle interaction has created challenges for prior testing systems to determine toxicity and the risk of products, and has highlighted a lack of fit-for-purpose nanoparticle testing (Hull and Bowman, 2010). More than this, there is currently a lack of skilled operators and equipment to test these aspects, and rationales for what things to test and why. Stakeholder decision-makers must engage with these challenges and decide how and what should be tested for nanoparticle products. They must also decide whether every type of nanoparticle needs to be assessed for toxicity or whether representative samples should be obtained and tested. In a 'perfect' world, all types of nanoparticle should be tested but in reality this is a daunting and virtually impossible task due to cost, lack of specialist equipment and analysts to determine results, and from a commercial perspective not appealing.

8.5.4. Defining Nanotechnology and Nanoparticles

At present no legal definitions exist, and with debatable rationales within law for which natural sciences definition of nanotechnology or nanoparticles to use. It is important to recognise that definitions cannot solve the problems created by these technology products, but that it can create a foundation of shared knowledge between different practitioners and academics. Without legal definitions, challenges are created for legal stakeholders who are engaged with nanotechnology and nanoparticle regulation, particularly for what these phenomena are. So far nanomaterials have been defined by science, fitting into a range of measurements at the nanoscale but posing the question for a measurement slightly outside this range (El-Shall and Edelstein, 1996). For example, should a product with a size of 101 nm be considered a nanomaterial? At present no, and there is often virtually no consideration of what the bottom end of the scale is. More than this though, there has been an assumption that nanomaterials are stable in size, which is often not the case, and through the process of Ostwald Ripening (Liu *et al,* 2007) the size may vary, moving products in and outside of the nanoscale range (Binion, 2008). While a single definition cannot hope to capture the essence of a nanomaterial, nanotechnology, or nanoparticles it should be there as a linguistic sign to aid in clarity and shared meaning. It should also function to facilitate decision-making, particularly where difficult decisions are faced for such complex and opaque technology.

8.5.5. Regulating Nanotechnology

Currently there are no specific regulations in place to mitigate risks from nanomaterials; instead current regulations across many product sectors are relied upon (Hansen, 2009). REACH has the potential to regulate nanomaterials through the one tonne weight limit for registration but there is a misconception that nanomaterials can be regulated in such a way. Depending on the nanomaterial, very few products will attain the threshold requiring registration. The view that REACH is suitable for nanomaterials is predominantly misguided and has failed to take into account the low weight of most nanotechnology

products. If 'unusually' a nanomaterial did reach a one tonne manufacturing level, then in principle it would be examined through REACH, depending on the product sector (Ward and Harley, 2010). Importantly, and at present there are thousands of nanomaterial products in the global market place where a 'wait and see' attitude has been dominant, meaning few fit-for-purposes product safety tests have been carried out, and with virtually no move towards a precautionary principle.

8.6. Regulatory Recommendations

After much examination and consideration of many themes arising from this study, this section draws multiple aspects together to highlight regulatory recommendations, to answer the main question driving this thesis of 'how should nanoparticles be regulated so that risk is minimised while business innovation and commercialisation is encouraged?'

As a starting point, the two main regulatory drivers are acknowledged, including facilitating the commercialisation of innovative products, while mitigating risk. Although it is easy to regard these drivers at opposite ends of a regulatory spectrum, I believe that this approach is unhelpful, as it is more pragmatic to regard them as 'hand-in-hand'. On this basis, the thrust for regulatory recommendations, are to contextualise, balance and promote both of these agendas to benefit the market and society, without the recommendation of overly prohibitive regulatory barriers. Following on with the notion of pragmatism, a fundamental overhaul of current regulatory systems is rejected as unhelpful, and very unlikely to be taken seriously.

At present, nanotechnology and nanoparticle products are regulated, but just not specifically as nanotechnology or nanoparticle products (Bowman, 2010). As discussed in this study, this has had advantages of rapid commercialisation but has left many questions unanswered for product safety and risk. Of course this does not mean to say that depending on a product being commercialised in a particular sector that there are no regulatory requirements, but that any testing

requirements are often based on pre-nanotechnology principles, where the ability to highlight toxicity, risks and adverse affects are potentially limited at present. Thus, I argue that there is a need for scientific tests to be developed that can determine the toxicity of nanoparticle products in line with current regulatory requirements based on the product application, and sector use. As an example, a nanoparticle therapeutic used as a pharmaceutical drug; there would already be a requirement for the regulation of product efficacy, safety, and quality. In practicality, I believe that there is no need to reinvent the regulatory 'wheel', and more simply, modify current regulatory requirements for more fit-for-purpose testing to determine nanoparticle safety, efficacy and quality. Following on with this example, challenges might well be raised for whether any nanoparticle product can receive an abridged route to market, on the future scenario that 'suitable' information exists for safety, efficacy and quality, coupled with a legal right to utilise this route. I am keen not to heavily use pharmaceutical drugs as an example, as this example is one of more stringent regulation than most other sectors, and would skew recommendatory discourse. This leads however to a pertinent aspect worthy of consideration, which is that with a pervasive collection of products, how should nanoparticles be regulated? It might make sense to regulate based on for example size, shape and application, which might further suggest the creation of obligatory registries, which is currently a contested arena. Although contested, and with much to be worked out for practical use, this idea has much to offer, particularly if data is collected throughout the life cycle stages of nanoparticle products, with a potential for higher-risk product applications having a similar system to pharmacovigilance reporting.

I believe that testing, reporting and cataloguing data is a vital aspect of addressing the aspect of risk and toxicity, which can lead to better regulatory decision-making. This is particularly pertinent for products, which might undergo Ostwald Ripening (changing, size and shape) resulting in different risks and toxicities along the life cycle, necessitating a holistic approach to testing at multiple product stages. A pivotal part of testing will no doubt be linked to whether it is perceived that nanoparticles can interact with other systems, such as

humans, or whether they are in essence ‘trapped’ and ‘safe’ within a product, with this aspect needing to be determined.

While there has been much discussion of the use of systems such as REACH to engage with testing nanoparticles, the lack of specifics for how to do so makes this unfeasible. More than this, there is no requirement to test products that are manufactured with a weight limit of less than one tonne, which at present I am unaware of any product reaching this limit, meaning no testing. In many ways, discussions regarding the use of REACH in its current regulatory format are trapped within a pre-nano style of thinking, based on classical bulk manufacture, which nanotechnology sits outside of. I therefore believe that nanoparticle regulations require not just a shift in scientific testing, but in the way that we think about products, based on ‘dated’ notions from the past century of how to manufacture and assess safety. Data must be collected that takes advantage of technology, enabling rapid collection and potential further assessment if adverse effects are noted. Due to the complexity of the challenge facing regulators, it is imperative that a wide variety of stakeholders from industry, academia, environmental groups and other areas work towards producing regulation that is specific, fit-for-purpose, and focuses on nanoparticles as not being a mirror image of bulk products for risk and toxicity.

8.7. Limitations and Recommendations

It is critical that the limitations of this study are examined, as they are an inherent part of the research process, and aid in a greater contextualisation and understanding of this study. As a starting point, it is recognised that contributions have been made to extant literature, but yet, as with arguably any research study, there are still limitations.

Throughout this study, the question remained, how to view this study, where there were clear multiple conflicting regulatory drivers, embedded within the disciplines of law and science. Attempting to engage with this aspect, which was through the non-neutral lens of myself, meant a synthesis of both legal and

scientific literature and 'thinking'. In practical terms, this created a challenge for which if any discipline should 'rule as king' and how successful any synthesis between subjects could be considered. Trying to balance the disciplines and regulatory views was no small undertaking, and resulted in many subjective choices being made. While through one perspective, it is a limitation; it has also brought to life a novel view for high technology regulation, where the study was constructed for the reader to engage with multiple conflicting aspects, while making overall sense of this complex area.

Beyond the critique of this study, I turned my focus to myself as a researcher, which was not something pulled together at the end, but was undertaken throughout this study, where I continually examined by perceptions and 'how' and 'why' I was taking any research stance. Prior to this study I had worked as a scientist manager carrying out commercialisation activities for nanotechnology products in many of the sectors examined in this study. This 'role identity' of me as a manager scientist had created a sensitisation to nanotechnology and the potential hype but also physical risks of such technologies. In practical terms, this meant that I was able to focus as an 'insider' through an emic stance of being 'one of the tribe' of individuals exploring the physicality of nanotechnology, while still be the researcher through contextualising this information through a legal lens, thus an etic stance (Kottak, 2006).

As this study sought to understand the regulation of nanoparticles as the vanguard of high technology R&D and product commercialisation, through inception, usage to end-of-life disposal, a heavy focus was made towards understanding the physicality of nanoparticles and the shortfall in law so far to have meaningfully engaged with these products, beyond overly simplistic discursive framings. While nanoparticles have been the focus they also highlight the regulatory challenges of many other high technology products particularly from the arena of nanotechnology. In this I argue that nanoparticles have acted as a reflective exemplar of high technology products and the challenges to 'know' what these products are and regulate based on product physicality.

This study has unpicked many challenges which in part are methodological and within the discipline of law. For example, prior examination of high technology products and sectors, including nanotechnology has demonstrated a potential lack of willingness for a host of regulatory actors to engage with the complexity and physicality of nanotechnology products. When comparing to other high technology arenas, such as pharmaceuticals, medical devices and biologics etc. this has not been the case, with an in depth and arguably more meaningful engagement particularly for product safety, efficacy and quality (Mann and Andrews, 2014). Thus the first suggestion for future work is that of a comparative analysis to be undertaken for these three other areas, which all deal with opaque, risk-laden and potentially harmful products, to determine what (if any) regulatory insights can be gleaned for safety, efficacy and quality. It is of course recognised that these other areas are within themselves much more heavily regulated, with ensuing costs and product lag times, but still set against a neo-liberalist driver of commercial innovation being a predominant aim (Abraham and Lewis, 2002). In practicality, these areas may have much to offer, as they all exist within a zeitgeist of needing to understand physical reactions from these products with their environment and users. Thus, notions of product physicality are not speculative, but driven towards being demonstrable through 'rigorous' scientific testing. While it might be argued that nanotechnology or these areas 'already' cover nanoparticle products, which is a wide claim, the very nature of nanotechnology products as being inherently unknowable for their safety and efficacy, challenges this notion.

Problematically, for a meaningful regulatory engagement with the physicality of nanoparticles and nanotechnology, greater efforts need to be made to embed regulatory theories within physical frameworks for how products interact with the world. At present, I suggest that law has predominantly taken a view to use a 'legal' lens from within itself to engage with the physicality of nanotechnology, at the expense of engaging with the specific nano aspects of the physicality of these products (Oberdörster, Oberdörster and Oberdörster, 2005; Beer *et al*, 2012). This of course is not to suggest that regulators should be 'in the lab doing science' but more that a greater consideration of the pivotal importance of product physicality should be made. Likewise scientific discourses have taken a

somewhat opposite view, where regulation is predominantly an issue of physicality, missing out many other regulatory aspects and drivers (Kjølberg, 2009). While both approaches have been insightful, they also have clear limitations, particularly for complex phenomena such as nanotechnology. It has to be made clear that both legal and scientific lenses are required to engage with nanoparticles and nanotechnology, and thus, the second suggestion for future work is to engage in a synthesis between disciplines, where regulation is viewed with both of these lenses in mind. This potentially grounds future work within a neo-liberalist framework of promoting innovation, but also more acutely considering wider regulatory aspects, through what might be considered a bricolage. Within itself, this is a perceptual change on the part of the researcher to more fully acknowledge the importance of knowledge from different disciplines, to get 'closer' to the phenomenon of interest, i.e. high technology, such as nanotechnology and nanoparticles.

Pivotal to any future work is a more critical approach towards the physicality of nanoparticles, which should be reflected in all of the main themes in this study, particularly for (1) risk and insurance, (2) health, safety and the environment, and (3) national and European regulations. I contend that only through this approach, will insights be drawn that will guide new testing required to understand product functioning, and that can echo throughout product R&D, commercialisation, usage and end-of life. Understanding the physicality of nanoparticles is paramount for 'capturing' their behaviour in a variety of environmental conditions, and for producing a clearer reflection between regulation and product physicality. The lack of consideration for the key physical process of Ostwald Ripening in any legal literature, which can result in nanoparticles changing their size and toxicity, is demonstrative of this aspect. Due to the potential of nanoparticles to change size and shape through the Ostwald Ripening processes, future work should explore this aspect for how a regulatory system can engage with products that dissolve into atomic forms, 'stay' as changeable nano-products or aggregate into larger products above the nanoscale.

Finally, the ability to use clearer language and have a usable definition of nano and related terms, for product physicality and regulation is required. Future work

should engage with this aspect for the production of a working definition. While there has been much discussion about the language of nanotechnology and nanoparticles, this has not extended much beyond etymology and tracing the use of words back to understand what nanotechnology means today. This is not a helpful approach, and is in many ways misleading. Although much consideration has been made towards nano definitions, it has often been through an overly simplistic lens of stating nano as being less than 100 nm, with no bottom limit, and a failure to engage with nano existing in a three-dimensional format, even at the nanoscale. Thus, definitions have misconstructed nanotechnology and nanoparticles, and for this to be rectified, language should be used as a refractive and reflective medium, simultaneously existing in between regulation and product physicality, while creating our interpretation of the physicality.

8.8. Personal Reflections

Before undertaking this study, my background had been within and utilised methodologies from the natural sciences and humanities, resulting in a mixture of quantitative and qualitative approaches to research studies. When using a natural sciences approach statistical methods to draw inferences from large populations to predict future outcomes were favoured. Alternatively, through the lens of a humanities researcher, my approach to social and physical life was through the analysis of the spoken word, transcribed, to enable textual analysis. Arguably this approach was most akin to this study, which was embedded within textual analysis, albeit without the transcription stage. Working with texts from different sources was thus not new to me, nor was the requirement to engage in interpretive analysis of documents and different author opinions. Importantly though, there are differences between my prior studies in humanities and this research. While engaging in this study and interpretive analysis, there was a lower level of embeddedness within ‘acknowledged’ and ‘referenced’ methodology, commonly engaged with by humanities and social science researchers (Bryman and Bell, 2011). More explicitly, while there is of course a research spectrum for analysing textual documents, and on the one side subjectivism, and the other objectivism, it appears to me that this facet is less

frequently engaged with by legal research than other areas, at least for acknowledged and referenced methodology. Within itself, this is not necessarily a problem, but for a new researcher such as myself in this area of legal studies, it created a challenge for unpicking the method for textual analysis. Facing this difficulty, and as acknowledged in the first chapter, I undertook to engage with an emic and etic approach (Kottak, 2006). In practicality, this meant a deep introspective and reflexive process, drawing on my knowledge from working within the nanotechnology sectors (an emic approach), as well as channelling findings through me 'the researcher' (at etic approach). Thus, and while engaging in a notional concept of content analysis, where prior corpus based textual analysis from within regulatory studies of high technology was unpicked, for wording, frequencies of thought, rationales and legal reasoning etc. to explicate this approach. Importantly, I make no ontological claim ('how the world or reality is'), but more that this study is a reflection of the phenomena studied, and grounded within elucidated regulatory structures (nanotechnology regulation).

By engaging with and carrying out this study, my opinions on many aspects of high technology regulation have changed, from those based on my experience from working within a nanotechnology company. At the start of the study, I worked within a paradigm (self, organisationally and sector constructed) that regulations were 'just' there to limit harm from 'dangerous' products. The more I engaged with the extant literature, the more my view shifted to one of a balancing act between promoting technological innovation and mitigating risk. However, at some level I now believe this to be another misconstruction, in that it is too simple a construction of high technology regulation. Instead, and imbibing the underlying neo-liberal premise that there are macroscale drivers for technology promotion and a need to mitigate risk, there are in fact, many competing and conflicting drivers, which regulatory systems are embedded within. Thus the two pronged scale of technology promotion vs. risk mitigation is helpful for an approximation, but misses many other important factors.

In practicality, while increasing my understanding of the complexity of high technology regulation, it has afforded the opportunity for me to engage with the

sponsoring company and meaningfully discuss the research findings from this study. This has led to many attitude shifts within the company, who have tried to utilise knowledge gained to more thoroughly consider the purpose of high technology regulation. In other words, regulation should be an inherent part of a high technology company's organisational life and identity, with many decisions being funnelled through this lens. As I work within the sponsoring company, this has meant that instead of decisions being made for a process, and then regulatory aspects considered at 'the end', they have been incorporated throughout the journey of a process. I believe that this has had the effect of making organisational members, more akin to regulatory stakeholders within the company, as greater knowledge is sought and implemented.

Finally, and on a more personal level, this study has enabled me to engage more meaningfully with high technology regulation, and as mentioned within the future work section, will enable further work to be carried out to utilise my knowledge sets from both the natural sciences and humanities, with future regulatory studies. As such this will allow questions based on how and why regulatory stakeholders within high technology companies engage with regulation, focussing for example on their discourses. Thus, this study will act as a platform for me to carry out further nuanced high technology regulatory research.

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