

Annex A Working Group, Review Group and Secretariat members

Working Group

The two Academies are extremely grateful to the Working Group for their hard work.

Prof Ann Dowling CBE FREng FRS (Chair)	Professor of Mechanical Engineering, University of Cambridge
Prof Roland Clift OBE FREng	Director of the Centre for Environmental Strategy, University of Surrey
Dr Nicole Grobert	Royal Society Dorothy Hodgkin Research Fellow, University of Oxford
Dame Deirdre Hutton CBE	Chair of the National Consumer Council
Dr Ray Oliver FREng	Senior Science and Technology Associate in the Strategic Technology Group, ICI plc
Baroness Onora O'Neill CBE FBA FMedSci	Newnham College, University of Cambridge
Prof John Pethica FRS	SFI Research Professor, Department of Physics, Trinity College Dublin and Visiting Professor, Department of Materials, University of Oxford
Prof Nick Pidgeon	Director of the Centre for Environmental Risk, University of East Anglia
Jonathon Porritt	Chair of the UK Sustainable Development Commission and Programme Director of Forum for the Future
Prof John Ryan	Director of the Interdisciplinary Research Collaboration on Bionanotechnology. Based at the University of Oxford
Prof Anthony Seaton CBE FMedSci	Emeritus Professor of Environmental and Occupational Medicine, University of Aberdeen and Honorary Senior Consultant, Institute of Occupational Medicine, Edinburgh
Prof Saul Tendler	Head of the School of Pharmacy and Professor of Biophysical Chemistry, University of Nottingham
Prof Mark Welland FREng FRS	Director of the Interdisciplinary Research Collaboration in Nanotechnology. Based at the University of Cambridge
Prof Roger Whatmore FREng	Head of the Advanced Materials Department, Cranfield University

Review Group

The two academies gratefully acknowledge the contribution of the reviewers. With the exception of Sir John Enderby and Mr Philip Ruffles, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release.

Sir John Enderby CBE FRS (Chair)	Physical Secretary and Vice-President of the Royal Society
Mr Philip Ruffles CBE FRS FREng (Vice-Chair)	Vice-President of the Royal Academy of Engineering and Chair of its Standing Committee on Engineering
Sir Richard Friend FRS FREng	Cavendish Professor of Physics, Cambridge University
Prof Nigel Gilbert FREng	Pro Vice-Chancellor and Professor of Sociology, University of Surrey
Dr James McQuaid CB FREng	Previously Chief Scientist, Health and Safety Executive
Prof Anthony Segal FRS	Department of Medicine, University College London

Secretariat

The core secretariat was: Sara Al-Bader, Dr Jofey Craig (June 2003 - September 2003), Dr Andrew Dunn (October 2003 – August 2004) and Dr Rachel Quinn at the Royal Society and Richard Ploszek at the Royal Academy of Engineering. Valuable administrative and web support was provided by Karen Scott-Jupp (Royal Society). The secretariat is grateful to the many other staff at the two Academies who contributed to the successful completion of this study.

Annex B Conduct of Study

Overview

The Working Group sought a wide range of views in the ways outlined below. Written evidence, and summary reports of workshops, meetings and other oral evidence sessions were posted on the dedicated website (www.nanotec.org.uk) as they became available, and comments on evidence was requested. The report has been prepared by the Working Group (listed in Annex A) on the basis of evidence collected and their own expertise. The report has undergone a rigorous peer review process by a review group comprising Fellows of both Academies (also listed in Annex A). It has been endorsed by the Council of the Royal Society and approved for publication by the Royal Academy of Engineering.

Evidence gathering elements

Initial call for views (June 2003)

The study was launched with an initial call for views that invited individuals and organisations to register their interest in this study and to identify the key issues that they thought should be considered by the Working Group. Over 90 responses were received.

Scientists/engineers workshop (30 September 2003)

The Working Group used this meeting to gather evidence from the scientific community (including industry) about the current state of research in nanotechnologies and both current and future applications of nanotechnologies.

Civil Societies workshop (30 October 2003 & 24 February 2004)

At this small workshop the Working Group consulted and discussed issues with a range of civil society organisations. The Working Group prepared questions or issues they wanted to discuss and participants had the opportunity to help set the meeting's agenda. The Working Group met with additional representatives on 24 February 2004.

Health and environmental impacts meeting (8 December 2003)

At this meeting the Working Group met with health and environment experts to consider the environmental applications of nanotechnologies as well as whether nanotechnologies might have a negative impact on human health or the environment.

Public consultation (December 2003 - March 2004)

To explore public attitudes to nanotechnology, the market research company BMRB International was commissioned to research public attitudes to nanotechnology. This involved two strands:

- Two in-depth workshops with members of the public were held in December 2003 to explore their ideas about nanotechnology, and to identify and discuss any potential concerns or questions that might arise.
- Three questions, designed to establish public awareness of nanotechnology were included in an Access omnibus survey in early January. The survey sought the views of 1,000 people in Great Britain aged 15+.

Workshop on regulation (11 February 2004)

The Working Group met with regulators and others with expertise in regulatory issues to discuss whether or not existing legislation is appropriate to nanosciences and nanotechnologies.

Industry meeting (3 March 2004)

This half-day meeting offered the Working Group an opportunity to further explore the issues covered in the terms of reference with industry representatives.

Dedicated website (www.nanotec.org.uk)

All interested parties (including the public) were able to comment via the website on any of the information posted on the website or raise issues relating to nanotechnologies in general or the about the study itself.

Independence

The study was conducted independently of Government, which was not involved in the selection of the Working Group members or its methods of working, and which did not view the report before it was printed.

Annex C List of those who submitted evidence

On 11 June 2003, the Royal Society and Royal Academy of Engineering issued a call for written evidence for the nanotechnology study. This was followed by a number of oral evidence sessions, meetings and workshops. Reports of these were posted on the website as they became available, and comments requested on them.

The following is a list of the individuals and organisations that gave evidence to the study in writing and/or orally. For ease of reference, evidence is listed according by individual and by organisation. The views of individuals do not necessarily represent those of their organisations.

The Royal Society and Royal Academy of Engineering are most grateful to those who assisted the study by providing evidence, and have made every endeavour to list them all here. If any individuals or organisations have been omitted we offer our apologies and will ensure that the web version of the evidence list is updated.

W = provided written evidence O = attended oral evidence session M = attended meeting or workshop

Individuals

A

Adams, Michael	Unilever (M)
Aeppli, Gabriel	London Centre for Nanotechnology (W &O)
Alakeson, Vidhya	Forum for the Future (W)
Albertario, Fabio (W)	
Aldrich, Tim	Forum for the Future (M)
Allen, Geoffrey	University of East Anglia (M)
Allen, Ray	University of Sheffield (M)
Alsop, Adrian	Economic and Social Research Council (W)
Altmann, Juergen	Experimentelle Physik II, Dortmund University (W)
Andrews, Arlan (W)	
Arnall, Alexander	Imperial College London (W)
Ayres, John	University of Aberdeen (W)

B

Bachmann, Gerd	Co-worker of a German Governmental nanotechnology funding agency (O)
Ball, Philip (W)	
Balmer, Richard	Association of Liberal Democrat Engineers and Scientists (W)
Barbur, Vicki	Eastman Kodak Company, USA (W)
Batchelor FREng, Keith (W)	
Besenbacher, Flemming	University of Aarhus, Denmark (O)
Biggs FREng, Simon	University of Leeds (W)
Binks, Peter	Nanotechnology Victoria (W)
Bosch, Wolfgang	Filtronic (M)
Bott, David	ICI (M)
Brazil, Rachel	Royal Society of Chemistry (W & M)
Briscoe, Brian	Imperial College London (M)
Broughton, Duncan (W)	
Brown, Mike	Boots (M)
Burgess, Doug	MOD (O)
Burgess, Jacquie	University College London (O)

C

Calladine FRS FREng, Chris	University of Cambridge (W)
Carroll, John	University of Cambridge (W)
Carson, Dave (W)	
Cass, Tony	Imperial College London (M)
Chadwick, Derek	The Novartis Foundation (W)
Chetwynd, Derek	University of Warwick (M)
Church, Colin	Department for environment food and rural affairs (DEFRA) (M)
Clarke, Andrew	Kodak (M)

Colbeck, Ian
Collis, Amanda
Cumpson, Peter

University of Essex (M)
The Biotechnology and Biological Sciences Research Council (W)
National Physical Laboratory (M)

D

Davey, Roger J (W)
Davies, Graham J
Davies FEng, Stewart
Delic, Julian
Dent, Benjamin
Depledge, Mike
Devine, Steve (W)
Dibb, Sue
Dimmock, John
Dobson, Peter
Donaldson, Ken
Dowding, Peter
Downing, Steve
Dransfield, Graham
Drexler, Eric
Duncan, Ruth

University of Birmingham (M) (W)
CEO BT Exact (W)
Health and Safety Executive (M)
Department for environment food and rural affairs (DEFRA) (M)
Environment Agency, Head of Science (M)
National Consumer Council (W&O)
Media Services Sussex Ltd (W)
University of Oxford, Begbrooke Science Park (W & M)
MRC Centre for Inflammation Research, University of Edinburgh (W &M)
Infinaeum (M)
ICI (M)
Uniqema (M)
Foresight Institute (W&O)
Welsh School of Pharmacy (W)

E

Eigler, Don
Ellis, John
Evans, Barry

IBM (O)
X-FAB UK Ltd (M)
University of Surrey (W)

F

Fenton, Gary (W)
Festing, Michael
Fisher, Andrew
Fitzmaurice, Donald
Fletcher, Amy L (W)
Flodstrom, Anders
Florence, Sandy
Foo, Joyce
Fox-Male, Nick
Fullam, Brian

Animal Procedures Committee (M)
University College London (M)
University College Dublin (M)
Royal Institute of Technology, Stockholm, Sweden (O)
The London School of Pharmacy (M)
FCO Singapore (W)
Eric Potter Clarkson IP Services (W)
HSE (M)

G

Gallop, John
Gann, David
Garnett, Martin
Gimzewski FEng,
James
Gittins, David
Glover, Anne
Golunski, Stan
Grant, Malcolm
Greisch, Edward R
Griffiths, Glynis
Grimshaw, David
Gubrud, Mark Avrum

National Physical Laboratory (M)
Imperial College London (W)
University of Nottingham (W)
Chemistry Dept, University of
California, Los Angeles (W)
Imerys (M)
University of Aberdeen (M)
Johnson Matthey (W)
Agriculture and Environment Biotechnology Commission (O)
US Military (W)
Food Standards Agency (M)
ITDG (M)
Center for Superconductivity Research, Physics Dept, University of Maryland (W)

H

Hanson, Robin
Harper, Tim
Harrison, Robert
Hawksworth, Stuart
Hayes, Emma

George Mason University, Fairfax, USA (W)
Cientifica Ltd (W & O)
Rouse Patents (O)
HSE (M)
Environment Agency (M)

Healey, Peter	Science Technology and Governance in Europe (W)
Higgins, Rob	Medicines and Healthcare products Regulatory Agency (M)
Hilsum, Cyril	University of Cambridge (W)
Hinde, Julia	FCO, Canada (W)
Hitchcock, Julian	Eversheds LLP Solicitors (W)
Holister, Paul	Cientifica (M)
Holtum, Dave	Engineering and Physical Sciences Research Council (W)
Hook, David	Medicines and Healthcare products Regulatory Agency (M)
Hossain, Kamal	National Physical Laboratory (W)
Howard, Vyvyan	University of Liverpool (M)
Howorth, Dave (W)	
Howse, Mike (W)	
Humphreys, Colin (W)	
Hurley, Fintan	Institute of Occupational Medicine, Edinburgh (M)
Hyde, Vic	Cosmetics Toiletry and Perfumery Association (M)
I	
Iden, Ruediger	BASF (M)
Illsley, Derek	Sun Chemical Co (M)
Ion, Sue	BNFL (W)
Irwin, Alan	Brunel University (O)
J	
James FEng, Jim (W)	
Janzen, William	Amphora Discovery Corporation (O)
Jones, Richard	University of Sheffield (W & O)
Juniper, Tony	Friends of the Earth (W)
K	
Karn, Barbara	US Environmental Protection Agency (W)
Kelly, Mike	University of Cambridge (M)
Khandelwal, Amit	Chemical Industries Association (M)
Knowland, John	University of Oxford (M)
Krauss, Thomas	University of St Andrews (M)
Kroto FRS, Harry (O)	
Kulinowski, Kristen M	Center for Biological and Environmental Nanotechnology USA (O)
Kumar, Dinesh	ION IT Ltd (W)
L	
Leigh, Beatrice	GlaxoSmithKline (M)
Light, Richard	DAART Centre for Disability and Human Rights (W)
Loveridge, Denis	Honorary Visiting Professor – PREST (W)
M	
Macaskie, Lynne	University of Birmingham (M) (W)
Martin, Philippe	EC Health and Consumer Protection (M)
Matthews, Kevin	Oxonica (M)
Maynard, Andrew	National Institute for Occupational Safety and Health (W)
McKeown FEng, PA (W)	
McLeod, Alistair	Imperial College London (M)
McQuaid, Jim (W)	
Mehta, Michael D.	University of Saskatchewan (W)
Meldrum, Maureen	HSE (M)
Merrifield, David	GSK (M)
Mesquida, Patrick	London Centre for Nanotechnology (M)
Miles, Glenn (W)	
Miles, Mervyn	University of Bristol (M)
Milner, Robin	UK Computing Research Committee (W)
Molyneaux, Andrea	Medicines and Healthcare products Regulatory Agency (M)
Mooney, Pat	Etc Group (O)

Moore, Julia National Science Foundation (M)
Morris, Vic Institute of Food Research (M)
Murray, Mike ABPI (M)
Murrer, Barry Johnson Matthey (M)

N

Northage, Christine Health and Safety Executive (M)

O

Ozorio de Almeida FCO, Brazil (W)

P

Pacholak, Anna FCO, Poland (W)
Palmer, Richard E University of Birmingham (W & M)
Palmer, SB Warwick Nanosystems Group, UK (W)
Parkinson, Stuart Scientists for Global Responsibility (W)
Parr, Douglas Greenpeace (W&O)
Parry, Vivienne (O) University of Strathclyde (W)
Pethrick, RA University of Cardiff (W)
Pham FREng, DUC ARM
Phillips, Ian Center for Responsible Nanotechnology (W)
Phoenix, Chris Ilford (M)
Pick, Martin (W) FCO, The Netherlands (W)
Pilkington, Ian Imperial College London (M)
Poirier, Natalie
Polak, Julia

Q

Quinn, Francis L'Oreal (M)

R

Rajan, Bob HSE (M)
Rayner, Steve Saïd Business School, Oxford University (O)
Richards, David Technopreneur limited (W)
Rickerby, David Advisory Cell for Science and Technology, European Joint Commission Centre (W)
Reip, Paul Qinetiq Nanomaterials Ltd. (O)
Rip, Arie University of Twente, The Netherlands (O)
Rix, Sam ex pupil of Hills Road Sixth Form College (W)
Roco, Mike National Science Foundation, USA, Senior advisor for nanotechnology also Chair
US Nanoscale Science and Engineering (W & O)
Roos, Ursula FCO, Germany (W)

S

Santoli, Salvatore International Nanobiological Testbed Ltd (W)
Savage, Nora Environmental Protection Agency, USA (W)
Schneemilch, Matthew Imperial College London (M)
Scott, Andrew Intermediate Technology Development Group (W)
Semple, Sean University of Aberdeen (M)
Sloan, Jeremy University of Oxford (M)
Smalley, Richard Rice University (O)
Smith, George University of Oxford (M)
Snape, Julian (W) University of Newcastle (M)
Snowdon, Ken Department of trade and industry (M)
Southerland, David
Stark FREng, Jim (W) Computing Research Committee (W)
Stepney, Susan UK
Stewart FREng, Will (W)
Stone, Vicki Napier University (M)
Sutherland Olsen, Dorothy (W)
Sutton, David ICI (M)

Swan, Harry
Symons, Rex
Syms, Richard

Thomas Swan & Co Ltd (M)
Better Regulation Taskforce (M)
Imperial College London (M)

T

Tran, Lang
Thomas, Jim
Tolfree, David
Tomlinson, Geoffrey (W)
Treder, Mike
Tsavalos, Alexander
Tuppen, Chris

Institute of Occupational Medicine, Edinburgh (M)
Action Group on Erosion, Technology and Concentration (W & M)
Technopreneur limited (W)
Center for Responsible Nanotechnology, USA (W)
Health and Safety Executive (W & M)
BT (M)

V

Vadgama, Pankaj
Vaughan-Lee, David
Vest, Charles
Visser, Germ W

Editor, Asia Pacific Coatings Journal (W)
Massachusetts Institute of Technology (O)
DSM, The Netherlands (W)

W

Wadey, Rita
Wakeford, Tom
Wang, Brian
Ward, Professor IM
Warheit, David B.
Weiss, Tilo
Wells FRS FREng, PNT
Whitby, Raymond
White, Ian
Whitesides, George
Wiggins, Jason
Wilkinson, Chris
Willett, Steve (W)
Williams, Gary (W)
Williams, Martin
Williams FREng, Richard
Williams, Simon
Wilsdon, James
Wilson, Neil
Windle, Alan
Winkler, Stefan
Wood, Stephen

OST (M)
PEALS (M)
Owner of a software company, Silicon Valley (W)
University of Leeds (W)
DuPont (W)
Sustech (M)
University of Bristol (W)
University of Sussex (W)
Chairman, scientific committee on cosmetic and non-food products (O)
Harvard University, Department of chemistry and chemical biology (O)
University of Oxford, Begbroke Science Park (W)
University of Glasgow (M)
Department for environment food and rural affairs (DEFRA) (M)
Institute of Particle Science & Engineering (W)
The Patients Association (M)
Demos (M)
University of Warwick (M)
University of Cambridge (M)
FCO, USA (W)
University of Sheffield (W & O)

Y

Yeates, Steve (W)
Young, Anthony R

St Johns Institute of Dermatology, Kings College London

Organisations

A

Action Group on Erosion, Technology and Concentration (W & M)
Advisory Cell for Science and Technology, European Joint Commission Centre
Agriculture and Environment Biotechnology Commission
Amphora Discovery Corporation
Animal Procedures Committee
Asia Pacific Coatings Journal
Association of Liberal Democrat Engineers and Scientists
Association of the British Pharmaceutical Industry
David Rickerby (W)
Malcolm Grant (O)
William Janzen (O)
Michael Festing (M)
David Vaughan-Lee (W)
Richard Balmer, Hon Secretary (W)
Mike Murray (M)

B

BASF group - Ruediger Iden (M)
Begbroke Science Park
University of Oxford - Peter Dobson (W & M), Jason Wiggins (W)
Rex Symons (M)
Amanda Collis (W)
Mike Brown (M)
Sue Ion (W)
Chris Tuppen (M)
Alan Irwin (O)
Better Regulation Taskforce
Biotechnology and Biological Sciences Research Council
Boots
British Nuclear Fuels
British Telecom
Brunel University
BT Exact (W)

C

Center for Biological and Environmental Nanotechnology, USA
Center for Responsible Nanotechnology, USA
Chemical Industries Association
Cientifica Ltd
Computing Research Committee (W)
Cosmetics, Toiletry and Perfumery Association
Kristen M Kulinowski (O)
Mike Treder, Executive Director (W)
Amit Khandelwal (M)
Tim Harper (W & O), Paul Holister (M)
Vic Hyde (M)

D

DAART Centre for Disability and Human Rights
Department for the Environment, Food and Rural Affairs
Martin Williams (M)
Department for Trade and Industry
Demos
DSM, The Netherlands
DuPont
Richard Light
Colin Church (M), Benjamin Dent (M),
David Southerland (M)
James Wilsdon (M)
Germ Visser (W)
David Warheit (W)

E

Eastman Kodak Company, USA
EC Health and Consumer Protection
Economic and Social Research Council
Engineering and Physical Sciences Research Council
Environment Agency
Environmental Protection Agency, USA
Eric Potter Clarkson IP Services
ETC (Action Group on Erosion, Technology and Concentration)
Eversheds LLP Solicitors
Vicki Barbur (W)
Phillippe Martin (M)
Adrian Alsop (W)
Dave Holtum (W)
Michael Depledge (M), Emma Hayes (M)
Nora Savage (W)
Nick Fox-Male (W)
Jim Thomas, Programme Manager and Pat Mooney (W, O & M)
Julian Hitchcock (W)

F

Filtronic
Food Standards Agency
Foreign and Commonwealth Office (W)
Wolfgang Bosch (M)
Glynis Griffiths (M)

Foresight Institute
Forum for the Future

Friends of the Earth

G

GeneWatch UK (W)
George Mason University, Fairfax, USA
GlaxoSmithKline
Greenpeace

H

Harvard University
Health and Safety Executive

I

IBM
ICI

Ilford
Imerys
Imperial College London

Imperial College, Business School and Department of Civil and
Environmental Engineering
Imperial College London Centre for Energy Policy and Technology
Infinaeum
Institute of Food Research
Institute of Food Science and Technology (W)
Institute of Occupational Medicine, Edinburgh
Institute of particle science and engineering (W)
Institute of Physics (W)
Intermediate Technology Development Group

International Nanobiological Testbed Ltd
ION IT Ltd

J

Johnson Matthey

K

Kodak

L

L'Oreal
London Centre for Nanotechnology

London School of Pharmacy

M

Massachusetts Institute of Technology
Media Services Sussex Ltd
Medical Research Council (W)
Medicines and Healthcare products Regulatory Agency

Eric Drexler (W & O)
Vidhya Alakeson, Principal Policy
Advisor (W), Tim Aldrich (M)
Tony Juniper (W)

Robin Hanson (W)
Beatrice Leigh (M), David Merrifield (M)
Doug Parr (W & O)

George Whitesides (O)
Julian Delic (M), Brian Fullam (M),
Stuart Hawkworth (M), Maureen
Meldrum (M), Christine Northage (M),
Bob Rajan (M), Christine Northage (M),
Alexander Tsavalos (W & M)

Don Eigler (O)
Steve Downing (M), David Bott (M),
David Sutton (M)
Ian Pilkington (M)
David Gittins (M)
Brian Briscoe (M), Tony Cass (M), David
Gann (W), Julia Polak (M), Matthew
Schneemilch (M), Richard Syms (M),
Alistair McLeod (M)
David Gann, Director Innovation
Studies Centre (W)
Alex Arnall (W)
Peter Dowding (M)
Vic Morris (M)

Fintan Hurley (M), Lang Tran (M)

David Grimshaw (M), Andrew Scott,
Policy and Programmes Director (W)
Salvatore Santoli (W)
Dinesh Kumar (W)

Dr Stan Golunski (W), Barry Murrer (M)

Andrew Clarke (M)

Francis Quinn (M)
Gabriel Aeppli, Director (W), Patrick
Mesquida (M)
Sandy Florence (M)

Charles Vest (O)
John Dimmock - Technical Director (W)

Andrea Molyneaux (M), Rob Higgins (M),

David Hook (M)
Ministry of Defence
MRC, Centre for Inflammation Research, University of Edinburgh

N

Nanotechnology Victoria
National Consumer Council
National Institute for Occupational Safety and Health (W)
National Physical Laboratory (W)
National Physical Laboratory

National Science Foundation US

Natural Environment Research Council
Novartis Foundation
Ntera UK Ltd (W)

O

Office of Science and Technology
Oxonica

P

Patients Association
PEALS
Policy, Ethics And Life Sciences Research Institute
Policy Research in Engineering, Science and Technology

Q

Qinetiq Nanomaterials

R

Rice University
Rolls Royce
Rouse Patents
Royal Institute of Technology, Stockholm, Sweden
Royal Society of Chemistry

S

Saïd Business School, Oxford University
Science Technology and Governance in Europe
Scientific committee on cosmetic and non-food product packaging (O)
Scientists for Global Responsibility
St Johns Institute of Dermatology, Kings College London
Sun Chemical Co
Sustech

T

Technopreneur limited
Thomas Swan & Co Ltd

U

UK Computing Research Committee
Unilever
Uniqema
Universitat Dortmund, Experimentelle Physik III
Université Louis Pasteur

Doug Burgess (O)
Ken Donaldson (W & M)

Peter Binks (W)
Sue Dibb, Senior Policy Officer (W)

Peter Cumpson (M), John Gallop (M),
Kamal Hossain (W)
Mike Roco, Senior Adviser NSF and
Chair of US Nanoscale Science,
Engineering and Technology (W & O),
Julia Moore (M)
Deborah Cosgrove (W)
Derek Chadwick (W)

Rita Wadey (M)
Kevin Matthews (M)

Simon Williams (M)
Tom Wakeford (M)
Tom Wakeford (M)
Denis Loveridge, Honorary Visiting
Professor (W)

Paul Reip (O)

Richard Smalley (O)
Mike Howse (W)
Robert Harrison (O)
Anders Flodstrom (O)
Rachel Brazil, Manager, Materials
Chemistry (W & M)

Steve Rayner (O)
Peter Healey, Coordinator (W)

Stuart Parkinson, Director (W)
Anthony R Young (M)
Derek Illsley (M)
Tilo Weiss (M)

David Tolfree (W)
Harry Swan (M)

Robin Milner and Susan Stepney (W)
Michael Adams (M)
Graham Dransfield (M)
Juergen Altmann (W)
Dorothy Sutherland Olsen (W)

University College Dublin
University College London
University of Aarhus, Denmark
University of Aberdeen
University of Aston

University of Birmingham

University of Bristol

University of California, Los Angeles, Chemistry Dept
University of Cambridge

University of Cardiff
University of East Anglia
University of Edinburgh
University of Essex
University of Glasgow
University of Leeds

University of Liverpool
University of Maryland, Dept of Physics
University of Napier
University of Newcastle
University of Nottingham
University of Oxford

University of Saskatchewan
University of Sheffield (W)
University of Sheffield

University of St Andrews
University of Strathclyde
University of Surrey
University of Sussex
University of Twente
University of Warwick
US Environmental Protection Agency
US Military

W

Warwick Nanosystems Group, UK
Welsh School of Pharmacy

X

X-FAB UK Ltd

Donald Fitzmaurice (M)
Jacquie Burgess (O), Andrew Fisher (M)
Flemming Besenbacher
Anne Glover (M), Sean Semple (M)
Peter Brett & Xianghong Ma, Peter J
Conley (W)
Richard E Palmer (W & M), Graham J
Davies (M), Lynn Macaskie (M & W)
Professor PNT Wells FRS FREng (W),
Mervyn Miles (M)
James Gimzewski FREng (W)
Chris Calladine FRS FREng (W), John
Carroll (W), Cyril Hilsum (W), Mike Kelly
(M), Alan Windle (M)
Duc Pham FREng (W)
Geoffrey Allen (M)
Ken Donaldson
Ian Colbeck (M)
Chris Wilkinson (M)
Simon Biggs FREng (W), Professor I M
Ward (W)
Vyvyan Howard (M)
Mark Gubrud (W)
Vicki Stone (M)
Ken Snowdon (M)
Martin Garnett (W)
Peter Dobson (M), John Knowland (M),
Jeremy Sloan (M), George Smith (M)
Michael D Mehta (W)

Ray Allen (M), Richard Jones and
Stephen Wood (W & O)
Thomas Krauss (M)
RA Pethrick (W)
Barry Evans (W)
Raymond Whitby (W)
Arie Rip (O)
Derek Chetwynd (M), Mr Neil Wilson (M)
Barbara Karn (W)
Edward R Greisch (W)

SB Palmer (W)
Ruth Duncan (W)

John Ellis (M)

Annex D Mechanical self-replicating nano-robots and 'Grey Goo'

Media coverage of nanotechnologies has invariably raised the spectre of the 'grey goo': a doomsday scenario in which nanoscale robots self-replicate out of control, producing unlimited copies of themselves, consuming all available material and ultimately laying waste to the planet. Whereas most of the scientific community considers this to be science fiction, others have argued that it is a possible outcome of unregulated nanotechnology. The level of public and media interest in nanotechnology therefore justifies the following question: Is 'grey goo' a real concern, or is it a distraction from the important issues?

The original concept of molecular manufacturing described by Dr Eric Drexler, Chairman of the Foresight Institute, imagined the synthesis of materials and objects by a mechanical 'assembler'; that is, a machine with the ability to make any object by selecting atoms from the environment and positioning them, one at a time, to assemble the object. This assembler can be programmed and is independently powered. As it can make any object, it can reproduce itself. If the process malfunctions or is corrupted, intentionally or not, the self-replication process could continue indefinitely. Over the past 20 years or so, Drexler and his colleagues have continued theoretical studies of the feasibility of such machines, but as far as we are aware there is no research in this field that has been supported by funding agencies, and there has been no practical experimental progress over this period. The reason is simple: there are many serious fundamental scientific difficulties and objections, to the extent that most of the scientific community believes the mechanical self-replicating nano-robot proposal to be impossible.

The scientific issues have been debated in open correspondence between Dr Drexler and Professor Rick Smalley, co-recipient of the Nobel Prize for Chemistry in 1996 for the discovery of carbon 60—so called buckyballs. In summary, there are two major difficulties: first, to lift and position atoms one needs very fine manipulators, of a similar size to the atoms being worked with; second, the atoms being manipulated must first attach – i.e. chemically bind – to the manipulator, and then unbind from the manipulator and bind to the object. Although scientists have used atomic force microscopes to manipulate a restricted group of individual atoms and molecules into simple structures on surfaces, the properties of matter on this lengthscale appear to be incompatible with the requirements for a mechanical self-replicating technology. These objections have been termed by Smalley as 'thick fingers' and 'sticky fingers'. Professor George Whitesides has questioned the feasibility of the energy management system that would be needed to handle the large energy input and release that occurs at the different stages of the construction process. Because the assembler is a nanomachine, its positioning accuracy is severely limited by the intense bombardment it receives from atoms in the environment – whether gaseous or liquid – which causes Brownian motion. It is quite clear: making a mechanical self-assembler is well beyond the current state of knowledge.

Our experience with chemistry and physics teaches us that we do not have any idea how to make an autonomous self-replicating mechanical machine at any scale, let alone nanoscale. Where we can find self-replicating machines is in the world of biology. The cell, thousands of nm in size, is the smallest unit we know that contains all the machinery essential for the process of reproduction, given a suitable environment. In fact, the planet we know today is quite different from its earliest form: biology evolved and turned a desert into the ecosystem of which we are now a part. At present however, the complete details of operation of even a simple cell are far beyond our understanding.

Given the above, we have heard no evidence to suggest that mechanical self-replicating nanomachines will be developed in the foreseeable future, and so would direct regulators at more pressing concerns outlined in chapter 8.

Quotations about mechanical self-replicating nano-robots and 'grey goo':

'I think there is no such thing as the assembler.' (Professor George Whitesides in evidence to the Working Group, with reference to the mechanical molecular assembler proposed by Dr Eric Drexler).

'My argument is that I believe that it is so implausible that I wouldn't worry about it...proving an impossibility is a very difficult thing to do and I've only done it in small parts.' (Professor Richard Smalley in evidence to the Working Group).

'... when people say "this isn't what we should be worrying about" I think they are right. I believe it's very much the wrong issue to focus on for a variety of practical and sensible reasons.' (Dr Eric Drexler in evidence to the Working Group).

Acronyms and abbreviations

AFM	atomic force microscope
AHRB	Arts and Humanities Research Board
BRTF	Better Regulation Task Force (UK)
BSE	bovine spongiform encephalopathy
CD	compact disk
CNT	carbon nanotube
CVD	chemical vapour deposition
DAMs	directed assembly of monolayers
DEFRA	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DNA	deoxyribonucleic acid
DH	Department of Health
DTI	Department of Trade and Industry
DVD	digital versatile disk
EA	Environment Agency
EBL	electron beam lithography
EC	European Commission
EINECS	European Inventory of Existing Commercial Substances
ELID	electrolytic in-process dressing
ELV	End-of-Life Vehicles Directive
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
FDA	Food and Drug Administration (USA)
FIB	focused ion beam
GDP	gross domestic product
GM	genetically modified
HRTEM	high-resolution transmission electron microscopy
HSE	Health and Safety Executive (UK)
ICT	information and communication technology

IT	information technology
ITRS	International Technology Roadmap for Semiconductors
LCA	life cycle assessment
µm	micrometre
MBE	molecular beam epitaxy
MEMS	micro-electromechanical systems
mm	millimetre
MOD	Ministry of Defence
MOCVD	metal oxide chemical vapour deposition
MRI	magnetic resonance imaging
MWNT	multi-walled carbon nanotube
NEMS	nano-electromechanical systems
NGO	non-governmental organization
NIST	National Institute for Standards and Technology (USA)
NPL	National Physical Laboratory (UK)
nm	nanometre
NONS	Notification of New Substances
NSF	National Science Foundation (USA)
OEL	occupational exposure limit
OLED	organic light-emitting diode
OST	Office of Science and Technology
POST	Parliamentary Office of Science and Technology
PV	photovoltaic
R&D	research and development
RCUK	Research Councils UK
REACH	Registration, Evaluation, Authorisation of Chemicals
RFID	radio frequency identification
RIE	reactive ion etching
SAM	self-assembled monolayer
SCCNFP	Scientific Committee on Cosmetic Products and Non-food Products intended for Consumers

SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SEM	scanning electron microscopy
SPM	scanning probe microscopy
STM	scanning tunnelling microscope
SWNT	single-walled carbon nanotube
TBT	tributyl tin
TEM	Transmission electron microscopy
UV	ultraviolet
WEEE	Waste Electrical and Electronic Equipment Directive