Setting the foundations for new industries and opportunities: Summary of an international panel report[1, 2]

1. Context

This substantial report on UK nanoscience policy was originally published in full in electronic form only on the RCUK website (http://www.rcuk.ac.uk/documents/nano/settingthefoundations.pdf); it is now available on the EPSRC website as well (http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/reports/NanoscienceReview2009.pdf). What was essentially the "executive summary" of the report, together with strategic recommendations for research priorities, is now published here so as to enable and encourage wider dissemination and debate on the important policy issues raised.

2. Introduction

Nanoscience and nanotechnology (NST) form an important part of the research portfolio of the UK Research Councils (RCUK). Success in these areas is vitally important for the long-term prosperity of the UK in the intensely competitive world of the 21st century. Multibillion[3] pound potential markets exist in areas such as healthcare, sustainability, security, clean energy generation, and information technology. In the autumn of 2009, an eight-member international Panel reviewed the NST research and development activities currently supported by RCUK. The Panel consisted of three UK academics, two UK industrial scientists (one from a large company, the other from a small–medium one), and three senior international representatives, from the USA, Korea and the Netherlands respectively (see box at the end of this section). The Panel reviewed a wide range of material, including a number of policy statements and strategic planning documents issued by the Research Councils and government departments; information on research grants awarded in this area; progress reports from grant holders; data on publications, patent applications and the creation of spin-out companies; citation data; and various measures

[1] This material was originally published as part of the Research Councils UK (RCUK) report "Nanoscience through Engineering to Application. An International Panel Review of Research Council Support for Nanoscience—Setting the Foundations for New Industries and Opportunities" (June 2010) and is reproduced with the permission of the Engineering and Physical Sciences Research Council (EPSRC).

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[3] U.S. billion; i.e., 10^9.

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to assess the overall impact of the work. In addition, a well attended nanoscience "Theme Day" was held in London on 23 September 2009. NST researchers from 27 UK universities took part, together with representatives of the Engineering and Physical Sciences Research Council (EPSRC), the Biotechnology and Biological Sciences Research Council (BBSRC), the Medical Research Council (MRC), the Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC), the Science and Technology Facilities Council (STFC), the Technology Strategy Board (TSB), and the Defence Science and Technology Laboratory (DSTL). The Panel focused on a set of broad strategic issues, which it regarded as being of major national importance for the UK. It looked at the programme as a whole, and asked: "What works"? "What does not work"? and "What needs to be changed, and how"? Comparisons were made between the UK programme and that of other countries with respect to both overall strategy and policy, and the outcomes of research. The Panel concluded that the UK has moved forward considerably since the last review was held in 2005. Many of the recommendations of that review had been implemented, and a more coherent core programme had been developed. However, other countries have moved ahead with greater vigour, and the UK's relative position had slipped back in certain key areas, rather than moving forward in the way that had been hoped for. Stronger direction and leadership of applied research, clearer and simpler lines of communication, better long-term support for strategic projects, and greater integration of all stages of the research and development cycle, are urgently required.

The Panel members were Prof. Laurence Eaves, Nottingham University, UK; Prof. James Gimzewski, UCLA, USA; Dr Victor Higgs, Applied Nanodetectors Ltd, Enfield, Middlessex, UK; Prof. Hanjo Lim, Ajou University, Suwon, Korea; Dr Rob Potter, Johnson Matthey Technology Centre, Reading, UK; Prof. Arie Rip, University of Twente, The Netherlands; Prof. George Smith, Oxford University, UK; and Dr Eugenia Valsami-Jones, Natural History Museum, London, UK.

3. What works?

(a) The basic concept of the strategic programme. RCUK has identified NST as a priority theme for UK research activity, and has established a cross-Research-Council programme: "Nanoscience through Engineering to Application". Much remains to be done: the funding level for this targeted programme is extraordinarily low when compared to other cross-Council priority themes and the funding available is ramping down during the later years of this spending review period (with estimated commitments of £5.5 million for 2009/2010 and £5 M for 2010/2011). The commitment of the individual Research Councils to the programme is also markedly nonuniform. However, the programme is nevertheless a welcome first step in the creation of a coherent UK strategy for NST research.

(b) Grand Challenges. NST offers the potential for major scientific and technological breakthroughs in a number of key wealth-creating areas. To make significant progress, focussed and sustained effort is required on a national scale. The Panel welcomes the three "Grand Challenge" areas that have so far been identified (Nanotechnology for Energy; Nanotechnology for Healthcare; and Nanotechnology for the Environment), the first two of which were funded in 2008 and 2009 respectively, and the third funded in early 2010. There was concern that the

funding for the Energy Challenge was very low indeed (£6.7 million) in comparison to the immensity of the scientific and societal challenges in this area. As a result, the programme had been tightly focused on the relatively narrow area of solar harvesting. The Healthcare programme was somewhat larger (£16.2 million) and attracted a large number of exceptionally high quality interdisciplinary applications, ten of which were funded in March 2009. This latter programme has particularly exciting prospects.

(c) Centres for Doctoral Training (CDTs). The recent funding of three major new CDTs (in Bristol, Cambridge and Manchester), which will provide integrated training programmes for graduates prior to embarking on individual research projects, is warmly welcomed by the Panel and by the research community. NST is inherently interdisciplinary, and such centres will play a pivotal role in training the next generation of leading-edge researchers.

(d) Shared Equipment Initiative. NST is a sophisticated activity, requiring routine access to expensive facilities, which cannot be made available on every university campus. EPSRC has made six awards (to Bristol, Cardiff, Leeds, Imperial College, Manchester Metropolitan and Nottingham Universities) to enable access by the wider academic community to existing specialist facilities in those institutions for construction, manipulation and examination of nanoscale structures and systems. This is an excellent initiative, welcomed by the community, and deserving greater development.

(e) Mid-range Facilities. A special programme has been announced to support the provision and operation of a network of more sophisticated facilities, costing approximately £3 million–£30 million each, based at individual universities, and offering nationwide services to UK researchers. Several of these facilities are, or will be, of major importance to NST, for example for specialist materials production and for nanocharacterisation. This network offers important new opportunities for UK NST research, and potentially offers excellent value for money. However, there is a lack of clarity about how users will pay for access to these facilities, and this issue needs to be resolved quickly. Funding uncertainties also need to be resolved swiftly.

(f) Access to large facilities. Very large installations such as the DIAMOND synchrotron and the ISIS neutron scattering facility at the Rutherford Appleton Laboratory provide outstanding, world-class resources for UK NST researchers. The feedback from the community was that the services provided by such facilities are excellent. There was particular praise for the "ticket system", by which researchers can apply for user time on these facilities, with (rapid) peer review of their application, without having to make a separate funding application. It is strongly recommended that this quick and efficient system should be adopted for the mid-range facilities as well.

4. What does not work?

(a) Strategic vision. At national level, and also at Research Council level, the system is top heavy with a labyrinth of advisory, consultative and coordinating committees. These impede decision-taking rather than facilitating it and create confusion both within the research community and at higher policy levels. This matter should be addressed urgently, building on the success of the close working relationship between the Research Councils and the Technology Strategy Board.

(b) Funding of the directed programme. The overall level of funding for the directed programme is very small in comparison with investment by competitor nations, too fragmented, and too short-term to have any possibility of making a significant impact on the future economic prosperity of the UK. Virtually all major advanced industrial nations are investing heavily in this field. There is a danger of the UK being left behind, especially in comparison with the rapid expansion of funding in countries such as the USA, Germany, Japan, Korea and China. Instead of exploiting our position as a knowledge-based economy, we risk becoming almost totally reliant upon imports of high technology goods and services in key strategic areas such as electronics, computing, and next-generation medical diagnostics and therapeutics. Our knowledge base is being eroded by the lack of funding in these important areas. The next five years will bring large changes in each of these sectors, with many exciting new products coming to market. It is vital that the UK should play a vigorous role in these wealth-creating activities, which are capable of giving a much-needed boost to the manufacturing sector of the economy.

(c) The six-year limit on funding for major (~£10 million) projects. The two Interdisciplinary Research Centres (IRCs) for nanoscience at Oxford and Cambridge, and the Interdisciplinary Research Collaboration on quantum information processing (QIP) are no longer supported by the Research Councils. Although set up as six year, fixed-term programmes, the Panel was disappointed by the decision to not offer further Research Council funding for each of these centres of excellence after the initial support expired. In each case, the teams of people involved represent a valuable reservoir of talent and experience, with huge potential for long-term success. For QIP, the lack of continuity of funding may prove highly damaging for future UK involvement in this strategically important field. Major new technologies of this kind cannot be created within short periods of time. A complete rethink of funding strategy is required to ensure longer term support for key initiatives like these.

(d) Weak links along the chain of innovation, from RCUK to TSB, to the Nanotechnology Knowledge Transfer Network (KTN), and on to individual UK companies. The Panel found it hard to identify evidence of joined-up thinking in the planning and execution of UK NST research. The initiatives announced by the various funding bodies have historically appeared almost completely disconnected. There have been no smooth pathways from laboratory bench to factory floor. In particular, there is little evidence of advance commitment by later-stage funding bodies, or other stakeholders, or investors, to take up the best results from early-stage research. This leads to the well-known "valley of death" scenario, in which the majority of potentially exploitable ideas never make it to the market place. The panel recognized that the role of the Research Councils only extends so far along the innovation chain but there is clearly more that can be done, working with later stage funders such as the Technology Strategy Board and the venture capital sector, to ensure that transformational NST research can achieve its potential. The panel noted some recent progress here where the RCUK programme was now working with the Technology Strategy Board to stage-gate[4] its portfolio of

[4] "Stage-gating" or "phase-gating" is a project management technique in which an initiative or project (e.g., new product development, process improvement, business change) is divided into stages or phases, separated by gates. At each gate, the continuation of the process is decided by (typically) a manager or a steering committee. The decision is based on the information available at the time, including the business case, a risk analysis, and the availability of necessary resources (cf. the Wikipedia article "Phase–gate model").

Grand Challenge research. However no such mechanism is currently open to the much larger portfolio of investment made through responsive mode. Internationally, better practice appears to be in Korea, where the overall NST strategy operates on a twelve-year time scale. The first five years of any major programme involve mainly basic research, the next five years require academic and industrial partnership, and the final two years are centred on industrial development. There is a rigorous process of evaluation at each stage of the programme, but continuity is assured for the most promising developments. Such a strategy optimises the prospects of success, and the UK should consider adopting a similar approach to supporting the research and development pipeline without delay. This will be particularly important in the light of impact agenda that researchers and Research Councils are increasingly being asked by Government to address.

(e) Lack of clarity regarding responsive mode support for NST. It is far from clear how much funding is being provided via responsive mode for NST research, because the current methods of labelling research in this category do not appear to be robust. This generates major problems when attempting to quantify overall expenditure on nanoscience, which is by far the biggest single element of the UK support structure for NST. Inevitably, there is a lack of clear distinction between certain aspects of research in chemistry, physics, materials science etc. and NST. Overlap is unavoidable, but relabelling of such core mainstream subject research as NST is creating budgetary confusion and the temptation to overstate the true amount of funding for such research. For instance, the EPSRC nanoscience programme landscape document[5] claims that almost 19% of EPSRC's total budget is invested in the area of NST, a figure that seems very hard to support. Clearer and more robust criteria are required for the assignment of costs within the NST programme, including the costs incurred in support of responsive mode proposals. Currently, it is not clear what criteria are used to decide whether a specific project does, or does not, fall within the remit of NST.

(f) Communication of strategy to the research community, and involvement of the community in policy-making. While the UK NST community has welcomed the evolution of a more coherent research strategy by RCUK, their feedback to the Panel reveals a marked sense of frustration about the detail. Many do not understand how programme priorities have been arrived at and do not perceive themselves to be part of the decision-making process. This undermines confidence in the system as a whole, and means that the knowledge and experience available within the community is not fully used when seeking to optimize research strategy. Greater effort needs to be made by RCUK to fully engage with the research community.

(g) Communication with UK industry. Industrial representatives were emphatic that the level of information that they were receiving about the UK NST research programme was inadequate. There were few relevant briefing meetings, little printed information, and a lack of the user-friendly web site where they could obtain news on the latest developments, obtain answers to queries, or find contacts with relevant university researchers. It is clear that Research Council programme managers would welcome feedback from industry regarding key areas where future research is needed. Better mechanisms need to be put in place to achieve this.

(h) Use of single-subject review panels to evaluate responsive-mode NST research proposals. Outside of the relatively small directed programme, the majority of NST research

[5] *EPSRC Nanoscience Landscape Document* (2009). http://www.epsrc.ac.uk/research/landscapes/Documents/LandscapeNano.pdf

proposals are evaluated by traditional programmatic peer review panels, which are often regarded as single-subject. This creates serious difficulties, because NST is inherently interdisciplinary. There is deep concern within the community that innovative NST proposals are failing at the review stage because they do not have sufficient support in any one traditional area of research. The value judgements made by referees and panels within this system are often perceived by the community as unduly narrow, and stifling to radically new ideas and concepts. The Panel recognized that this criticism is not exclusive to NST research and could be applied to multidisciplinary research more generally.

(i) Environmental, health and safety aspects of NST research. The conventional peer review process presents particular problems for those who wish to carry out precautionary research on environmental or health aspects of NST, hence work in this area is taking a long time to get established in the UK. Proposals to investigate the toxicity of nanoparticles are perceived to fare badly, because reviewers do not regard either the toxicology or the nanoscience as being sufficiently innovative, even though the combination of methodology and application may be novel. For example, proposals to provide standard reference nanomaterials for such studies do not score highly under the heading of innovative research, despite the fact that the supply of such well characterized materials is vital to underpin the whole field of safety-oriented research.

5. What needs to be changed, and how?

(a) Leadership and direction. Provide strong, clear leadership and direction. Simplify the management structure for applied research through the abolition, pruning or merger of the multiplicity of committees that are holding back NST research in the UK. It will be imperative to set clear scientific and technical goals for the next five to ten years; making oversight of UK NST a direct responsibility of the Government's Chief Scientific Adviser might facilitate a joined-up approach to this, as would providing more structure to the role of the RCUK Strategic Advisor for NST. In the original (2005) proposal, the holder of this post was envisaged as having a leadership role. In practice, the function has been downgraded to one of advice, liaison, and external communication. This falls short of the executive leadership function that is essential for national success.

(b) Funding arrangements. Prioritize applied research funding in the key strategic areas of healthcare, sustainability, security, clean energy generation and information technology. Improve the overall design of the funding system for key strategic projects. A long-term, interagency funding strategy is required for the development of major new technologies. This needs to be coupled with a rigorous stage-gating process, to ensure that only the very best and most appropriate projects are allowed to continue to the next phase of development.

(c) Coordination. Improve links between the Research Councils, TSB and other agencies of the Department of Business, Innovation and Skills (BIS) and with the business and investment community. Obtain up-front commitments from all stakeholders to ensure continuity of support for important long-term programmes of national strategic importance so that they can be seen through from start to finish, without the policy and funding gaps that are so painfully evident at present. Responsibility for driving this programme forward should be taken at ministerial level, with the task assigned to a specific minister within the BIS team.

(d) Communication. Vigorous efforts need to be made to improve communication within

the NST research community itself, between the research community and the funding bodies, between the scientific and industrial sectors, and between innovators and investors. A whole raft of measures could be beneficial, most of them very straightforward, such as a central web site; a directory of current research; easier online access to key research publications and patents; regular informal meetings to encourage interaction between researchers from different disciplines; blogs for better and more frequent communication between individual researchers, and between researchers and industrial companies; regular "road shows" to exhibit highlights of the research programme to regional companies; and a series of broader technical information meetings for the investment community. At present, no single person or organization has overall responsibility for coordinating or leading such activities and, hence, little progress is being made. A senior staff member within the Research Councils should be assigned this task and given the appropriate support to enable it to be achieved. An important first step to ensure that future NST policy development reflects the views of the research community should involve the submission of findings from this review to BIS to inform the further development of the policies set out in "UK Nanotechnologies Strategy—Small Technologies, Great Opportunities", published in March 2010.[6]

(e) Peer review. A more flexible, more interdisciplinary approach is required to the review of responsive-mode proposals in the NST area. There is a need to encourage proposals that are bold, adventurous and unconventional as well as interdisciplinary. The introduction of more cross-disciplinary, cross-Research-Council panels may help here, along with the trialling of new initiatives, such as fast-track, proof-of-principle funding, to give radical new ideas the opportunity to demonstrate their potential quickly before more extensive funds are committed to their support. The community have a key role to play here as they own the knowledge and the judgments that support the peer review system.

(f) Precautionary research. A fundamentally different, cross-Research Council approach is needed in order to permit adequate commissioning of the precautionary research that is vital to the public acceptance of NST. Key goals should be identified, and consideration given to ring-fencing funds in order to achieve them. This topic could also be considered as a further potential "Grand Challenge" area for the UK NST community.

6. Strategic recommendations for research priorities[7]

In the overall strategy for Research Council support of NST, it is important to preserve an appropriate balance between responsive mode funding for groundbreaking "blue-skies"

[6] *UK Nanotechnologies Strategy—Small Technologies, Great Opportunities* (2010). http://bis.gov.uk/assets/biscore/corporate/docs/n/10-825-nanotechnologies-strategy

[7] One Panel member, Prof. Laurence Eaves, did not feel able to endorse the full recommendations outlined in the report. In his view too much emphasis was placed on top–down management of NST research in the report and its recommendations. Prof. Eaves feels that history tells us that ground-breaking developments (e.g., graphene, polymer electronics etc.) have often emerged from the work of small university research groups, funded by modest responsive mode grants, recognition of which is not reflected in the report. Prof. Eaves feels that there is currently insufficient evidence that Grand Challenges and Interdisciplinary Research Centres and Collaborations in NST have led to major research breakthroughs and he does not agree with the Panel's views in the report about such initiatives. He feels that the recommendations lack a strong statement in support of responsive-mode funding; which needs particular nurturing in the present

research, and managed programmes for more applied and targeted research. By definition, the occurrence of disruptive and transformational advances in the basic science cannot be predicted beforehand. All that can be done in that sector is to provide a research environment which is conducive to such discoveries, and an organisation and management structure which is well adapted to translating the results of such research into new products, services and processes. In the more applied sector, which involves managed programmes, it is necessary to set priorities and to identify areas where the greatest benefits are likely to be obtainable, whether in scientific, technical, economic and social terms. Areas where NST has multibillion pound development potential, and which should be given top priority for applied research programmes within the UK, are:

1. Healthcare: diagnostics, therapeutics, targeted drug delivery, assisted living.
2. Sustainability: achieving greater functionality with less use of raw materials and energy.
3. Security: ultra-sensitive sensors, detectors and encoding systems.
4. Clean energy generation: more efficient photovoltaics, thermoelectric materials, and fuel cell catalysts.
5. Nanoelectronics: faster and more versatile computers and communications systems, and for quantum information processing.

adverse economic environment where it is unreasonable to expect new large financial stimuli to support managed initiatives. He would also oppose the suggestion that the UK adopts a Korean-style model of funding for NST, feeling such a model to be ill-suited to the UK research environment.