TECHNOLOGY INNOVATION AND SOCIETY

Published Quarterly for the Information of Subscribers Autumn 1999

FOUNDATION FOR SCIENCE AND TECHNOLOGY

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THE JOURNAL OF THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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Volume 15, No. 3 Autumn 1999

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Technology, Innovation and Society is published quarterly by the Foundation at an annual subscription of £40, including postage. Single copies £13 each.

It is also circulated to all Learned Societies and Institutions accredited to the Foundation as part of the services provided to them.

We would welcome items of news, letters and articles, which should be submitted to the Editor for publication in future issues.

Typesetting by *Light Touch Typesetting.*

Electronic page assembly by *LPS, London.* 0207-394 6920

Printed by *Aztec Press, Cardiff.* 01222-464614

ISSN 0951-2918

THE SIXTH ZUCKERMAN LECTURE

The Office of Science and Technology Department of Trade and Industry with the Foundation for Science and Technology held the Sixth Zuckerman Lecture at the Royal Society on 30 June 1999. The subject was “Science and Technology in the 21st Century” and the speaker was Dr Neal Lane, Assistant to the US President for Science and Technology. The event was sponsored by British Aerospace plc and Pfizer Central Research. The Lord Sainsbury of Turville, Parliamentary Under Secretary of State for Science, and The Rt Hon The Lord Jenkin of Roding presided.

SCIENCE AND TECHNOLOGY IN THE 21st CENTURY

Dr Neal Lane*

Summary: Dr Neal discussed changes that were under way in US science and technology policy that reflected the philosophy behind the Vice-President’s January 1999 challenge to the scientific community. He had called for “a new compact between our scientific community and our government” that was based on rigorous support for fundamental science, along with a shared responsibility “to shape our breakthroughs into a powerful force for progress”.

Introduction

I am grateful to Sir Robert May for inviting me to be the speaker at the last Zuckerman Lecture of the 1900s. Sir Robert and I share an occupational hazard. Serving as science advisor to a national government requires one to garner public acceptance on two fronts simultaneously: as a scientist and as a policy specialist. The people of the United States and the United Kingdom seem increasingly sceptical in both areas. Witness the following episode.

A man flying in a hot air balloon suddenly realizes he’s lost. He reduces height and spots a man in a field. He lowers the balloon farther and shouts, “Excuse me, sir, can you tell me where I am?” The man below says, “Yes, you’re in a hot air balloon, hovering approximately 30 feet above this field”.

“You must work in science”, says the balloonist.

“I do”, replies the man. “How did you know?”

“Well”, says the balloonist, “your answer is technically correct, but it’s of absolutely no use to anyone”.

The man below replies, “You sir must work in policy”.

“I do”, replies the balloonist, “but how’d you know?”

“Well”, says the man, “you don’t know where you are, or where you’re going. You’re in the same position you were before we met, but now it’s my fault”.

As science policy advisors, Sir Robert and I would seem to be challenged in both regards. My remarks tonight are offered to counter those views.

This evening, I will talk about changes under way in US science and technology policy that reflect the philosophy behind the Vice President’s January 1999 challenge to the scientific community. Speaking before the annual meeting of the AAAS, Vice President Gore called for “a new compact between our scientific community and our government – one that is based on rigorous support for fundamental science, along with a shared responsibility to shape our breakthroughs into a powerful force for progress”. I will briefly note the trends that are influencing the existing compact, discuss how the US has been responding in terms of S&T policy, and say a few words about where we are headed!

Trends that influence the future of science and technology

Most people, in America – and perhaps in the UK – now take for granted the advances in science and technology that have yielded economic prosperity, good health, a cleaner environment and enhanced national security. We, both the scientists who do the research and the taxpayers who fund and benefit from our work, have settled into a fairly comfortable routine of investment and payback that has served us well for many years. But foment in the current political, economic and social backdrop, as well as within science and technology, suggests we cannot simply maintain the status quo if our nations are to prosper in the 21st century.

Perhaps the most remarkable trend is the increasingly rapid pace of change in science itself. We see it in Nobel Prize-winning achievements such as the cooling and trapping of atoms that led to the successful creation of Bose-Einstein condensates and atom lasers and in the work of Harry Kroto of Sussex University, in partnership with my former colleagues at Rice University, in the discovery of fullerenes. We also see it in the cloning of “Dolly” – the sheep with the Mona Lisa smile; in the remarkable advances in human stem cell research, and in the impressive progress on the Human Genome Project, in which the Wellcome Trust is playing such a major role. Another breakthrough – GPS – will likely make the story I just told about the balloonist obsolete in a few years, since it’s almost unimaginable that anyone could be lost anywhere on Earth.

Perhaps no area has contributed more to this acceleration of science and technology than information technology. The Internet, specifically, symbolizes the influence of science and technology on the societal trends that now affect the future of science and technology. In less than a decade, this one tool of modern information technology has exploded from a network of fewer than 100 sites – researchers communicating with computers and with one another – to a network of networks, including the World Wide Web, with more than 100 million users of all ages, nations and walks of life who apply it to all sorts of purposes. The Internet continues to grow – in size and scope, in terms of commercial influence and in terms of cultural impact. I very much appreciate the perspective of Thomas Friedman, who in his new book, *The Lexus and the Olive Tree*, suggests that we are now operating in a system that has replaced Cold War geopolitics – symbolized by a wall that divided everyone – with globalization – symbolized by the World Wide Web, which unites everyone. Vice-President Gore announced last week that the US will partner with ten developing countries and the World Bank to provide technical assistance and expand

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Internet access, which will further unite us. He invites other interested countries to join this initiative as well.

There is no end in sight for advances in science and technology or for their impacts on society. Sir Robert best summed up my assessment of what we can expect in the 21st century when he said, "Tomorrow's world will be even more different from today's than today is from yesterday. The change will derive, in unforeseeable ways and on uncertain time scales, from advances in fundamental understanding of how the world works".

The pace and scope of scientific advances create new challenges for us in the policy area. Boundaries between traditional disciplines, and even between science – the world of ideas – and technology – the world of tools – have blurred. Myriad demands on resources have upset the *status quo* at institutions conducting research and development. Young people – in the United States, at least – continue to spurn science and technology careers, in part because our primary and secondary schools provide such a poor base of understanding in mathematics and science. We may find our population unable to cope with change of the type Sir Robert describes.

Steps the US has taken in S&T policy to adapt to changing trends

Despite the swirl of change around us, doing good science in the 21st century will likely require the same basic elements we have depended on in the 20th century. We will still need curious, creative and capable minds to perform tomorrow's science and engineering. We will still need young people who are passionate about science and mathematics and are committed to careers in S&T. We will still need strong and stable government support for S&T, including a solid core of basic research, particularly in institutions of higher learning. And we will still need high-quality facilities and instrumentation to carry on the kind of research that will lead to the next century's breakthroughs.

The challenge, then, is how to maintain these prerequisites when everything else is changing. I want to talk now about three areas of science and technology where the Clinton-Gore Administration has increased support in response to changing trends: 1) what I will call "broadly enabling" fundamental research; 2) policy-relevant research; and 3) research on the ethical, legal and social implications of advances in science and technology.

In the United States, the federal government has an undisputed role as an investor in fundamental research. Our commitments to that realm of inquiry are deep and sustaining. But broadly enabling research – research that asks fundamental questions and at the same time is likely to yield progress in many scientific fields and technologies – is receiving top priority. And history leads us to expect this research to produce gains in the economy and progress toward many other social goals. In the fiscal year 2000 budget request, President Clinton and Vice President Gore made basic research on information technology – including all aspects of computing and communications – the top priority because information technologies fulfil three critical functions:

First, these technologies allow us to vastly accelerate the pace of research and discovery across all scientific fields.

Second, they have become key drivers of the economy. During the past five years these technologies have contributed one-third of America's economic growth.

Third, information technologies are essential for achieving some of our most important overarching public goals, from health care to education to protecting our environment and maintaining national security.

The President's information technology initiative, if funded by Congress, will provide a $366 million increase (28%) in Federal IT research. Much of the new funding will support long-term fundamental research, particularly software, but also very high-risk, long-term research on concepts such as quantum computing and DNA computing. The initiative will also support advanced computing infrastructure. We hope to provide to the non-defence research community a network of computers approaching the cutting edge of technology with regard to power (in the Teraflop domain) and associated support services. Finally, the proposed initiative would greatly expand research into social, economic and workforce impacts of information technology.

I believe there is bipartisan support for enhanced investment in information technology. But I anticipate a long, hot summer awaiting the results of our appropriations process.

In addition to support for "broadly enabling" research, the Clinton Administration has also increased support for policy-relevant research – research designed not only to extend the frontiers of science, but also to produce the information we need for wise policy decisions. Nowhere is the need for a sound science base clearer than in the area of environmental policy.

Take, for instance, the debate over climate change. All stakeholders in this debate have used science in many legitimate as well as questionable variants to support their arguments. For that reason we have dedicated ourselves in international and domestic forums to identifying the types of data that decision makers need, determining where our current knowledge base provides answers or simply raises new questions and, finally, undertaking the research deemed most likely to provide the relevant facts.

When we approach the task of writing policy-relevant questions for climate change, nothing leaps out as particularly revolutionary or mysterious. For instance, a policy-relevant, but policy-neutral, question identified for the Intergovernmental Panel on Climate Change is: "What are the evidence for, causes of and consequences of changes in the Earth's climate since the pre-industrial era?" Scientists know a lot about the answers to that question, but it can completely stymie a policy debate if, for whatever reason, people do not hear the answers. Policy-relevant questions do not change the nature of the research so much as they focus the researchers on the need to translate their results into "plain English" – or, perhaps, "plain American", in our case – and the need to fill in gaps in the knowledge base.

In the United States, we have adopted this same emphasis on policy-relevant questions in our nationwide effort to study and understand the potential regional consequences of climate variability and change. We have based the assessment on the principles of scientific excellence and adopted an open and participatory approach linking scientists and a broad spectrum of stakeholders who care particularly about a state or region of the country – that we believe will produce much more influential results than an "ivory tower" undertaking limited solely to input from experts.

Indeed, I think it is not an overstatement to say that science has left the ivory tower and entered the marketplace, which means our results will more and more often have ethical, legal and social implications that deserve our increased attention. Recent advances in biomedical science, particularly, promise so much for society, but also raise serious ethical questions and challenge deeply held beliefs.

For example, the successful cloning of Dolly, rapidly followed by the successful cloning of mice and cows, raised the possibility – and the fear – that successful cloning of a human being was not far behind. This prospect, understandably, rubs most people the wrong way: technically, because current cloning methods have high fatality rates and the survivors often have abnormalities, but, fundamentally, because we are uncomfortable ethically, morally and emotionally with the concept of producing clones of ourselves.

Similarly, society stands to benefit enormously from potential therapeutic use of human embryonic stem cells to treat debilitating and currently incurable diseases. However, for many people, that potential does not mitigate the fact that human embryos are destroyed in the process of obtaining these stem cells.

In the United States, we have encouraged open discussion of cloning and stem cell research under the guidance of an independent advisory group – the National Bioethics Advisory Commission – that operates in the "sunshine", meaning that it takes and responds to public comment, and all meetings are open to the public. Your own Human Genetics Advisory Commission recently issued a report on cloning and stem cell research that made an important contribution to the international discussion of these issues, by drawing a distinction between therapeutic and reproductive cloning that will help frame the continuing debate in the coming months. Last week your government reaffirmed its opposition to the use of cloning technology for human reproduction. The US government expects to receive NBAC's recommendations shortly, and, of course, the President will consider them carefully before reaffirming or changing US national policy.

We have also begun to incorporate funding for research that will help us anticipate and respond to the ethical, legal and social implications of advances in science and technology in the very beginning stages of projects. Earlier I mentioned the special focus of the President's information technology initiative on the social, economic and workforce impacts of information technology. We have also set aside funds to answer similar questions raised by the Human Genome Project. In the United States, funding for this type of research – focusing on the human aspects of science and technology – is likely to receive more attention in the future.

Additional steps needed to shepherd S&T into the 21st century

Each of the areas of focus I have been discussing – "broadly enabling" research, policy relevance and ethical, legal and social implications of advances in science and technology – is a work in progress. We know we have much more to do.

I believe additional dimensions require our attention as well. Among these dimensions of science and technology, education, S&T partnership and public understanding lie at the heart of what Vice President Gore referred to as the "compact" between the science and technology community and the American public as represented by its government. This unwritten agreement on "who does what?" and "who pays?" when it comes to scientific issues was first formalized by the science advisor to Presidents Roosevelt and Truman, Vannevar Bush, in his book *Science: The Endless Frontier*, right after World War II. The compact has evolved over the past 50 years, and clearly requires renewed attention to enliven it for the 21st century.

Education – a very high priority in the Clinton-Gore Administration – is an element of the compact that needs particular attention. The Administration has taken steps to ensure that all students have educational opportunities of the highest quality open to them, and we have emphasized opportunities involving mathematics, science and technology.

Yet, as we near the 21st century, we are still unable to attract a broad and diverse group of individuals to the science and technology workforce. And we find the performance of our students from kindergarten through secondary level disappointing in international comparisons.

Yes, there has been progress. No, it is not nearly enough. To make the kind of progress we really need, we must have consensus either on a new, more aggressive role for the Federal government or on a modified role for our partners in academia, in the private sector and in State and local government.

It is not clear that an enhanced Federal role is the best tack. It would be expensive. And our partners would likely regard it as intrusive on their domains if we do not first seek consensus on our goals and methods. Those with a more immediate role in the education of the next generation – universities and colleges, State and local governments – may well be the ones who need to take a more aggressive role in making sure that public goals are attained. In any case, this is an area where revisiting the compact is critical.

Education is just one place where partnership among the stakeholders is a key to exerting influence. Many S&T objectives are accomplished through partnerships – involving Federal, State and local levels of government, universities, industry, international organizations and multiple combinations of these institutions – which must adapt to changing times.

One recurrent bugaboo in the United States involves the blurry line between science and technology that I referred to earlier. There is general agreement that technologies moving to the marketplace are in the sphere of the private sector. But when cutting-edge science can lead almost instantaneously to marketable technology, where do you draw the line on government involvement?

One example is the broad area of information technology. Advances in search algorithms or security protocols can have immediate value to Internet-based firms. When I ask Congress for IT research funds they want to know why industry is not taking responsibility for this research. We know firms do conduct some basic IT research, but it is difficult for individual companies to obtain the full benefits from their investments, often because the timing is not optimal.

Biotechnology, particularly in the search for new drugs and better agriculture, also poses some difficult questions. In these areas basic research raises the spectre of commercial advantage, through genetic engineering and other technologies. Even if we resolve issues related to funding of pre-competitive and competitive technologies, we still must take proper account of public opinion and societal values. I will return to biotechnology – especially to comment on genetically modified organisms – in a moment.

Therefore, given the importance of partnerships, we must ask some policy-relevant questions. What kinds of partnerships do we need to provide the appropriate pre-competitive research that makes specific, marketable advances possible? How can we create standards that facilitate movement to the marketplace? Is there a way – through policy – to ensure that we take proper account of the concerns and values of the public? Revisiting the compact may not answer all our questions about partnerships, but constructive dialogue among the partners should steer us in the right direction.

Scientists are, perhaps, the senior partners in the compact between science and society, at least in terms of responsibility. And there is something I would ask of scientists in the way of change, as well, something that I believe will go a long way towards improving public understanding of science and technology. That is to become what I will call civic scientists.

For a vivid example of such a scientist, we need only invoke the namesake of this distinguished lecture series, Lord Zuckerman himself, whose training in the life sciences made him valuable to the British government in researching the biological effects of bomb blasts at the start of World War II. For several decades after the War, he extended his scientific training and expertise to social and civic applications, including serving as the first Chief Scientific Advisor to the British government – a most noble calling, I might add.

I believe that even more so than in the past, scientists and engineers must get visibly involved in societal issues in their communities, in their states and at the national level. But the case for the civic scientist applies just as forcefully at the international level, for two reasons. The first is the universality of scientific knowledge. And the second is the dramatic and accelerating internationalization, or globalization, of science and technology.

The best science depends on cross-fertilization of the best minds, without regard for political boundaries. I must take this opportunity to say that I am deeply troubled by the current climate of panic and isolation that has gripped the US Congress in the wake of breaches in security at one of our national laboratories. National security is a serious matter, but an over-reaction threatens the very core of scientific progress – free exchange of ideas. I am dedicated to maintaining open doors for civilian research even as we increase security for classified information. Secretary Richardson is taking steps to do just that.

But, as I started to say, we need global cross-fertilization – open exchange of ideas and a commitment to working together as civic scientists – to deal with issues where the science is moving quickly towards the marketplace and where the public no longer blindly accepts authority. Science, policy and politics have converged in many such areas in recent years, but I would like to briefly address one that has become a very sticky wicket around the globe – genetically modified organisms.

Today, almost 20 years after research on the little-known Agrobacterium resulted in the first successful and dependable genetic transformation system for crops, desirable genes from any species can be modified to function not just in other plants, but in specific tissues at specific times. That advance opens the door for new opportunities to enable resistance to diseases and pests, drought tolerance, improved nutritional properties and other beneficial traits that can be used to improve consumer health, protect the environment and increase the farmer's bottom line. Biotechnology is no miracle solution. But with over 800 million malnourished people in the world today, those are very attractive capabilities.

However, with capability comes responsibility: responsibility for regulatory agencies to protect human health and the environment through a process that is open and inspires public trust; responsibility for industry to develop products that benefit the consumer and the environment; and responsibility for consumers to thoughtfully hold government and industry accountable for their decisions and ensure that those decisions are based on sound science.

That third responsibility is a loud clarion call for the civic scientist. As scientists we need to communicate risks and benefits clearly to the public and respond to their concerns. Against the backdrop of the media – which vary dramatically in their respect for facts – the work of the civic scientist is desperately needed. It is our responsibility to work with the media, civic organizations and other outreach mechanisms to make sure consumers have the information needed to make informed decisions. People need to feel confident that their food is safe, wholesome and good value for their families. Consumers deserve nothing less than transparency in the science policy debate and our very best efforts at public education. I am certain that public understanding will be a major objective of the US National Academy of Sciences and the Royal Society when they meet on this topic in July.

Conclusions

We have made a good faith downpayment on the challenge from the Vice President to develop a new compact between science and society:

- Broadly enabling research, exemplified by the information technology initiative, has taken top priority on our agenda.
- Researchers have integrated stakeholder interests in their projects, increasing the policy-relevance of their work.
- Ethical, legal and social implications of advances in science and technology now starting to get the attention they deserve from the outset of research.
- Education – the single most important factor for continued prosperity and closing the gap between the "haves" and the "have nots" – has become the primary focus of all parties to the compact.
- Partners in the S&T continuum – from academia, business and government at all levels – have reassessed their goals and explored how they will join efforts to make a whole greater than the sum of the parts.
- Instead of hitting the snooze button, scientists are responding to the wake-up calls brought on by GMOs and other contentious science policy debates and working with the public to achieve better understanding of the power and limits of science and technology.

We have a lot of work left to do. But our vision – a continuing stream of scientific advances, fuelling technological developments that will improve the economy and the quality of life for everyone in the next century – keeps us going.

I collect what my office refers to as a "Jetsons" file of speculations on the future of science and technology. It's named in honour of a popular cartoon show about life in a futuristic space age. These "opportunities" have sustained me and my White House colleagues through many a long, dark day of budget battles. Nothing is more satisfying than imagining developments in the 21st century that may mean that:

- People will be able to visit Mars – with our advanced understanding of aging, perhaps me amongst them.
- Trees will be able to convert sunlight to liquid fuel and deliver the fuel directly from their root systems to underground pipelines.
- Various types of MEMS – microelectrical mechanical systems – will be able to get long-distance communications costs down practically to zero, or be assembled into robotic organisms that hunt for survivors in collapsed buildings, or deliver drugs directly to diseased tissue. And 1,000-fold further down in miniaturization, nanotechnology is on the horizon.
- Someone finally – especially after Dolly has shown us what females can do on their own – will give us the answer to that urgent question, "why should males exist?"

Before concluding, I want to pause to take note of an approaching milestone – not a millennium, not a century, but a bicentennial. Next year will mark the observance of the 200th anniversary of the election of Thomas Jefferson as the third US President. Jefferson revered science and exploration, and chartered the Lewis and Clark Expedition – an exploration of the American West, whose impact on society he could scarcely have imagined. I can think of no more fitting way to honour Mr Jefferson than by committing to 21st century expeditions in science and technology that simultaneously push the frontiers of knowledge and improve people's lives.

I am fortunate to work for a President and a Vice President who share a compelling vision of the power of science and technology and a commitment to use those tools to prepare for the 21st century. Bill Clinton said last year that he foresees in the next 50 years:

"A world where climatic disruption has been halted; where wars on cancer and AIDS have long since been won; where humanity is safe from the destructive force of chemical and biological weapons, wielded by rogue states or conscienceless terrorists and drug runners; where our noble career of science is pursued and then advanced by children of every race and background; and where the benefits of science are broadly shared in countries both rich and poor".

The past 50 years have been exceptional times for science and technology. I look forward to working together with all of you, particularly because of the special ties between the US and the UK – but also with our colleagues around the world – to achieve the kinds of changes outlined by the President for the next 50 years so that people come to look at such progress as typical rather than exceptional.

In closing I want to share a story I heard about "old England" – maybe someone can tell me whether it's true. There was a budget debate among the faculty at an Oxford college. The dons were debating what to do with all of their college's money. Most seemed to agree that buying land would be the best use for the money, since, as one faculty member observed, "for the past thousand years, land has proven to be a very wise investment for the college". At this point, the college's whiskered old patriarch stood and said, "True, but the past thousand years have been atypical".

Indeed, for our two nations, and our world, the past 1,000 years, past 100 years, even past 10 years, have been atypical. And that's a good thing. Let's work together on another century of changes even more marvellous than those we see today. Let's work to ensure that as we continue on this accelerating spiral of progress in science and technology, we involve our citizens much more directly than we have done in the past. Let's make sure that all people around the world better understand the issues, participate fully in decisions about how to deal with risks and, especially, enjoy all the benefits offered by science and technology.

SCIENCE & FOOD IN THE 21st CENTURY

The Foundation held a lecture and dinner discussion on 11 May 1999 at the Royal Society. The subject was "Science and Food in the 21st Century" and The Rt Hon Lord Jenkin of Roding was in the chair. The speakers were Professor Christopher Leaver FRS, FRSE, Department of Plant Science, University of Oxford, Professor Alan Gray, The Institute of Terrestrial Ecology, and Professor Derek Burke CBE, DL, Adviser to the House of Commons Science and Technology Committee.

Summary: Professor Gray discussed the major environmental issues and scientific challenges surrounding the introduction of genetically modified crops into UK agriculture. Professor Burke examined the reasons for the strong public reaction arising from newspaper headlines about GM foods and asked what scientists could do about it. He suggested that the issues were wider than just GM, for they bore on the wider question of how our society uses science to create wealth.

ENVIRONMENTAL ASPECTS OF GROWING GM CROPS

Professor Alan Gray*

Introduction

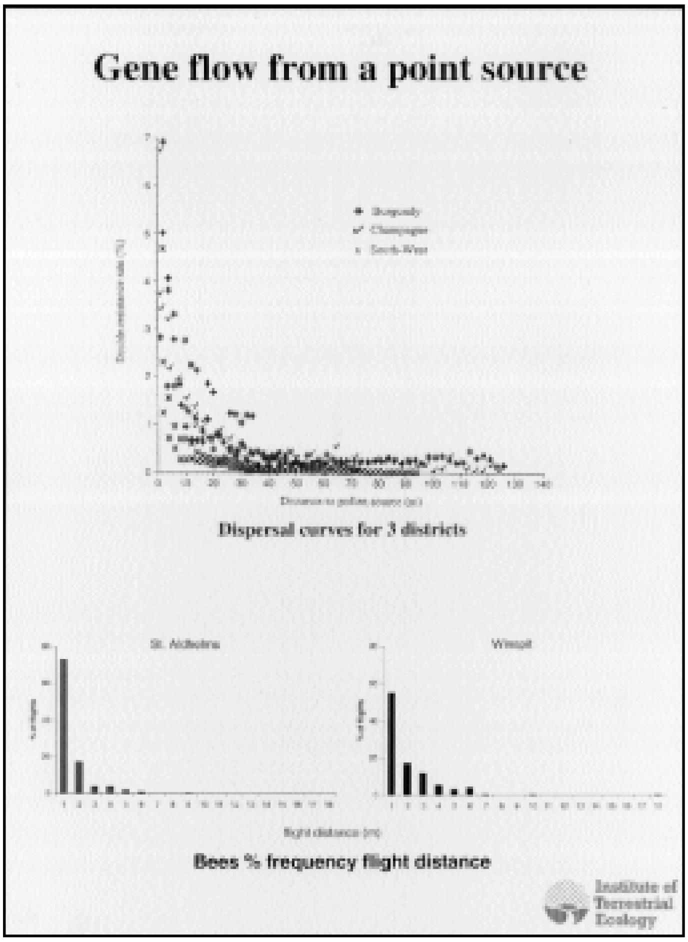
Your Director implied I should sacrifice detail to the cause of comprehensiveness and so I will try to mention, albeit briefly, at least the major environmental issues and scientific challenges surrounding the introduction of genetically modified crops into UK agriculture. Perhaps the four key issues are gene flow, gene escape, effects on non-target organisms and farmland biodiversity. They are ranked roughly in order of immediateness and degree of impact so that, for example, changes in the plant or animal species composition of farmed landscapes resulting from say, growing herbicide-tolerant crops, are probably the most delayed, cumulative and subtle – and certainly present us with the greatest problems in trying to define the term "environmental harm" (a definition which is arguably needed for formal risk assessment).

Gene flow

First, then, gene flow. I'm sure you will have seen the extensive media coverage, of which there was more this morning, of questions about how far genes travel, especially in pollen. Their potential to transfer over long distances to natural populations and, in one famous case, to organic sweetcorn, has been raised under banner headlines (which frequently use emotive words such as "genetic pollution" or "contamination"). Well, how far do genes travel, and what are the consequences?

One problem with gene flow is highlighted in Fig. 1. These two examples happen to show (top) hybridisation rates with distance in transgenic herbicide-tolerant oilseed rape (as the evocative names indicate, in different regions of France), and (bottom) the average pollinator (here, bumblebees) flight distance in two wild cabbage populations (in Dorset); but I could have chosen almost any others from the literature to illustrate the typical dispersal distribution curve. The best mathematical description of the curve will vary from species to species, depending, eg, on the breeding system and the way it is pollinated, but in the essentially sessile world of adult plants, the great majority of matings, hybridisations, seed dispersal, disease transmission events, etc., happen between near-neighbours – usually within a metre or two. They then fall rapidly according to some exponential power function. However, these leptokurtic curves typically have a long tail, with gene flow occurring at vanishingly rare frequencies, sometimes over considerable distances. This long tail has been the focus of much attention!

Empirical data of this type have been extremely useful in managing the risks of gene flow from small-scale R&D trials of GM plants and continue to help us to derive appropriate isolation distances for specific plots and fields of particular species. However, they are likely to be of limited utility where GM crops are grown on a commercial scale, year after year. Recent studies at the Scottish Crops Research Institute have helped to quantify gene flow among fields and feral populations of spring oilseed rape on a regional scale (in the Carse of Gowrie (Tayside)). A combination of empirical studies using bait plants and pollen traps and of modelling of pollen concentration has indicated greater genetic con-



▲ *Fig.1. Gene flow*

* *The Institute of Terrestrial Ecology*

nectedness in space (and through persistent ferals, in time) on a regional scale than might be expected from studies based on single-source fields.

This does not surprise those of us who have been working on the movement of genes in natural populations of crop relatives. In some work from our laboratory by Alan Raybould and colleagues, we have been measuring gene flow between linear populations of wild cabbage and sea beet along the Dorset coast. Gene flow is estimated from the spatial distribution in these populations of neutral marker genes (using classical population genetics theory). It turns out that gene flow declines with distance more quickly in the insect-pollinated wild cabbage than in the wind-pollinated sea beet. From the relationship between degree of gene flow and distance, one can calculate the point at which populations become genetically isolated (roughly where there is less than one migrant gene per population per generation). In cabbage this is at about 6km, in beet at around 13-15km, although there is a great deal of variation.

The important point about such studies of persistent populations, whether in regional fields or natural populations, is that they emphasise that for some crops grown on a large scale year after year, gene escape (or transgene escape) is at some scale inevitable. In applying the classic risk evaluation paradigm

RISK = EXPOSURE (or probability) x HAZARD

for certain crops grown at certain densities we simply must assume that the probability is 1 (although it will be considerably less) and get on with assessing the nature of the hazard – or, more exactly, the consequences of gene flow. Importantly, for example in the case of herbicide-tolerance in oilseed rape, that is what was done in ACRE.

In the meantime, we must continue to treat isolation distances for trials according to their scale, and on a crop-by-crop, construct-by-construct basis.

Gene escape

How, then, might genes escape? Transgenes can escape from the crop if the plant they occur in persists in the field as a volunteer or escapes into the peri-agricultural and wider countryside. For example, potatoes frequently volunteer from last year's tubers, and oilseed rape volunteers from spilled seed. Oilseed rape also commonly establishes feral populations – as do many other escapes from cultivation, including lucerne, chicory and probably even wild cabbage, which the Romans are thought to have introduced to Britain and which is now naturalised on coastal cliffs. Our flora has many similar examples which we now happily regard as naturalised or even native.

The key question to address in assessing the risks from volunteer or feral escapes is: "Will the genetic modification alter the biology of the plant in a way which will make it volunteer more, or more successfully, or become more invasive or persistent as a feral plant?".

Thus, in an agronomic situation we must assess whether herbicide-tolerant volunteers present a risk which cannot be managed, either by the use of alternative herbicides or by other agronomic practices. In the case of plants being more invasive or persistent outside the crop where, say, herbicides are not being used, the search for potentially increased weediness can include both carefully designed experiments and modelling (and increasingly for many crops, the vast natural experiments from growing, by next year, some 60 million hectares of GM crops in the world).

If I may give examples of this from our own work and tell you about an experiment designed to ask the question: "What if feral oilseed rape populations are protected from insect and mollusc herbivores?". We did it using chemicals rather than transgenic plants. In a large replicated experiment, plots of oilseed rape were regularly sprayed with either molluscicide, insecticide, both, or water. The experiment showed that it is possible to dramatically increase plant number and seed yield if you protect such populations from slugs and snails, flea beetles, pollen beetles, cabbage weevils, and so on. In the insecticide treatment the number of seeds per m^2 was increased three-fold compared to the control. However, and crucially important, recruitment to these experimental populations in the following year indicated that seed and seedling mortality was so great (birds/mice/vertebrate herbivores, fungi in seedbanks) that the differences in population size could not be related to treatments. Increased fecundity is not necessarily increased weediness.

In fact, data from such experiments can be used to ask "Which introduced traits are likely to most increase population persistence or weediness?" One promising approach, being developed by James Bullock at ITE, has been to use matrix models which look at the different life-history stages of plants and see how population growth rates (the parameter λ, which measures the difference in numbers between years) are affected by changes in the transitions from one stage to the next (what proportion of seeds become seedlings, seedlings become adults, and so on). By artificially increasing in the model each character value, one can test the sensitivity of each stage and its influence on λ. One such model shows, in oilseed rape, the importance of seed survival to population increase – indicating that in this species risk assessment should be targeted on how the introduced trait affects seed predation, survivorship in the seedbank and germination. In fact, ecologists here and in the USA have increasingly taken exactly that targeted approach (with, for example, transgenic oilseed rape of high laurate content).

I must abandon this level of detail, but I wanted to demonstrate that, in addition to the data from R&D trials provided by the breeders and experience from other countries, there are ways of anticipating the problems and doing relevant research.

Transgenes can also escape from some crops by hybridisation and introgression with wild relatives. In this country, the crops where the probability of such gene flow is high include sugar beet, cabbage, ryegrass, clover, carrot, apple, plum and poplar – all these crops have been modified by modern biotechnology somewhere in the world. Of course, there are crops where this form of gene escape is not an issue – maize, potatoes, wheat, tomatoes, strawberries, and so on. There is a third group where the wild relatives are not members of the same species but of the same genus or plant family. These include lettuce, barley and oilseed rape.

There has been considerable interest in hybridisation of oilseed rape with its various wild relatives – especially wild turnip (*Brassica rapa*). Wild turnip can be a troublesome agricultural weed in some countries – notably Denmark. In England, it occurs mostly in a semi-natural habitat where it lives under the pseudonym of Bargeman's cabbage, growing alongside canals and streams. Interestingly, the rates of hybridisation and introgression between these two species turn out to be very different in agricultural and semi-natural situations. Where wild turnip plants occur as single or small groups of plants in rape fields, more than 60-80% of them produce hybrid seed, whereas even where wild populations in the Thames Valley were within a metre of the edge of the rape crop, work at the University of Reading showed that between 0.4% and 1.5% hybrid seed were produced.

These huge differences in hybridisation rates are easily explained in terms of the breeding systems of the two plants and the different frequencies in which they are combined (turnip is a self-incompatible diploid ancestor of oilseed rape).

The interesting question is not "Which estimate of gene flow is correct?" – clearly both are – but "Which number would make you change your mind about the risks of growing transgenic oilseed rape: 50%, 10%, or even 1%?". Whilst scientists rarely ask that question explicitly, we should be under no illusions that others do – usually to support or attack the technology. (And of course, having a number informs our judgement but does not remove the need for judgement whether the forecast tells us we can expect some showers or that there is a 20% chance of rain, we still have to decide whether to take a picnic.)

The possible transfer of genes to wild relatives opens up a whole set of questions for environmental risk assessment. Typically of ecological questions, they frequently lie along the critical path of risk assessment. Detailed understanding may be some way off, although issues of safety and environmental harm are probably more easily addressed in the shorter term. Again, the key constructs are those that affect the ability of the plant to invade or persist – the so-called "fitness" traits. We can think of several among the next generation of modifications for stress tolerances, e.g. salt-, drought-, frost-tolerance.

There are also several traits among the current generation of transgenes which may increase the fitness of wild plants, especially by the mechanism of "ecological release" – the release of a population from the regulating influence of its natural enemies or pathogens. Expression of the various insecticidal and antifeedant proteins come into this category (eg Bt, protease inhibitors, lectins, antifungal hydrolases, etc.). Genes for virus-resistance, in which, with colleagues at the Institute of Virology and Environmental Microbiology at Oxford, we have become particularly interested, present us with several scientific challenges.

Non-target effects

Because of time constraints, I must gloss over the issues of soil microbial effects and of non-target species: suffice it to say that the possible presence of insecticidal proteins constitutively expressed on a large scale raises interesting questions for soil decomposition processes and for effects on predators and beneficial insects. Laboratory experiments feeding ladybirds on aphids which have fed on potatoes expressing a snowdrop Lectin gene, and feeding lacewings on cornborers fed on Bt maize, have received much media attention and have been incorporated into the risk assessment for these crops. I am happy to discuss these in debate.

Farmland biodiversity

I want instead to turn finally, and briefly, to the complex issue of farmland biodiversity.

Almost 75% of the UK land surface is farmed in some way (compared with 46% in the USA and 8% in Canada, which may partly account for different cultural attitudes to GM crops), and what we do on our farms directly affects our rural landscape and its wildlife. Indeed, our most prized habitat-types, such as species-rich chalk downland or heathland, are products of human activity and agriculture.

UK Government, as part of its obligations under Article 6A of *The Convention on Biological Diversity*, produced in 1994 the *UK Biodiversity Action Plan*, which commits Government to conserve and, where possible, enhance biodiversity within the UK by encouraging land management practices which benefit wildlife. At the same time, the decline in farmland wildlife, notably farmland birds, over the last 20-30 years has drawn attention to the impact of agricultural changes on diversity. Both the Government's statutory advisers (English Nature) and NGOs such as the RSPB have drawn very public attention to the fact that the introduction of herbicide-tolerant crops could accelerate the decline in farmland wildlife. Of course it could. But it might not. It might actually benefit wildlife.

For this reason, it is crucially important that the farm-scale trials of a range of herbicide-tolerant crops, beginning this year, are conducted not only with scientific rigour (as I'm sure they will be), but also in an atmosphere in which minds remain open. Those who have jumped quickly to the facile explanation that herbicides and pesticides are solely to blame for the loss of birds not only overlook many other changes in farming in recent decades but also fail to understand ecology or what ecologists do. Trained to seek the most parsimonious explanation, we rarely encounter ones which involve a simple, single factor.

By one of those strange coincidences, I happened to see a paper yesterday in the current issue of the *Journal of Applied Ecology* which illustrates my point beautifully. It provides, in a study from Denmark, a clear demonstration of the impact on the weed flora in rotational fields of growing either winter or spring cereals. Surveys in experimentally-managed crop margins (1988-1992) revealed a significantly greater density of weeds, and a greater number of different species of weeds, in spring-sown compared to winter-sown cereals. Furthermore, more of the species in the spring-sown crops were from plant families (Fabaceae and Polygonaceae) which are important for arthropod herbivores. When we think that the many changes to farms, such as hedgerow removal and the return of predators, also include in many areas a switch to autumn-sown crops, the effects described in this study are especially interesting. The relative effects of the different changes are simply not well enough known to isolate one as the key factor.

Environmental risk assessment for the introduction of GM crops, compared with that, say, for introducing new chemicals where we can quantify dose, exposure, half-life, and so on, is a relatively inexact science. Those of us involved in it must be careful with our words. We must not confuse variability with uncertainty, or uncertainty with risk of harm. We must not dogmatically rule out rare events, or give guarantees that an event will never happen. If we do not know, we must say so. We must remember that we are usually dealing with probability – a phenomenon notoriously misunderstood by the public, and which cigarette smoking and the National Lottery clearly demonstrate has a tier of value judgements of the risks and benefits above that of the best scientific judgement. My hope is that we continue in the 21st Century to adopt that vital blend of commonsense, pragmatism and sound judgement based on good science that, even in the face of pressure amounting at times to hysteria, has served us well, I believe, up to now.

Professor Derek Burke CBE DL*

The derailed debate

Introduction

This evening, we have concentrated on the promise – and the problems – offered by genetically modified foods and crops, for this pervasive new technology is going to bring about many changes in the future. However, it's had a very bumpy start and for months now there has been a sustained press campaign to discredit GM foods and, in particular, against GM soya – a campaign which may well have succeeded: for the major food manufacturers and retailers in the UK have all recently discontinued its use. What is going on and why?

The newspaper headlines tell the story, and omitting those about Dr Pusztai, whose story surfaced on February 12th, let me give you a selection of recent headlines:

Can 'Frankenstein' foods harm your unborn baby? *Daily Mail* 30/01/99

Chefs warned on genetic foods. *Guardian* 01/02/99
Food in the shadow of Dr Frankenstein. *Daily Mail* 04/02/99
This terrifying tampering. *Daily Mail* 08/02/99
Put a five-year ban on Frankenstein food. *The Mirror* 13/02/99
The prime monster. *The Mirror* 16/02/99
Is baby food really safe? *The Express* 17/02/99
Fast Food giants bin mutant grub. *Daily Star* 19/02/99
The mad forces of genetic darkness. *Sunday Times* 21/02/99

Note the evocative language and the frequent scaring images.

Rats and the Rowett

The whole campaign was then accelerated by a press release, on February 12th, supporting Dr Pusztai's claims that feeding GM potatoes to rats damaged their immune systems and caused pathological damage to the gut, claims originally made last August. He maintains that his results showed that genetically modified foods

* *Adviser to the House of Commons Science & Technology Committee*

could cause damage, and he implied that the present regulatory processes were inadequate, so that we could not be sure that GM foods were safe. Twenty scientists from 14 countries announced their support for Dr Pusztai, and in an accompanying Greenpeace Press Release, the possibility was raised that the damage claimed by Dr Pusztai might not be due to the lectin – the gene that had been added – but to the virus promoter that has been used to control the activity of many of the new genes that have been inserted into plants. This raised the possibility that the damage claimed by Dr Pusztai might be a general response to other GM foods.

This made such front page headlines as "Alarm over 'Frankenstein' foods" (*The Daily Telegraph*) and "Food scandals exposed" (*The Guardian*). It quickly became a major news item on radio and TV, and in all the newspapers, but Government remained unmoved by calls for a moratorium, the Prime Minister writing personally in *The Telegraph* of February 20th under the headline "GM foods: we stand firm". Other scientists voiced criticisms of the claims, calling for appropriate control experiments and speculating that the process of inserting the lectin had "disrupted the behaviour of the potatoes' other genes", while several companies pointed out that their own toxicity tests would have picked up the sort of effects claimed by Dr Pusztai. Professor Tom Sanders, a Professor of Nutrition in the University of London, published a thoughtful, critical review in *The Independent* on the 19th of February, while a full review by The Royal Society is soon to be published. Then some of the original twenty scientists explained that they were supporting Dr Pusztai because they thought he had been poorly treated, not because they were necessarily against genetic modification and one said specifically the he was "not acting as a referee" (*New Scientist*, March 6th, p. 13).

What conclusions can be drawn in the meantime? Let me suggest two. First, that the case for damage to rats in long-term feeding trials is, on published evidence to date, at the most 'non-proven'. Second, that scientists should never speak to the media about work which is clearly so controversial before having had their results and the interpretation cleared by their scientific peers. This had not been done. Indeed, much of the damage caused by this report, even if it is untrue, cannot be undone; the idea that feeding GM potatoes causes damage to rats is now part of the general folklore, as shown in a recent "Have I got News for You".

Why has the public reacted so strongly?

So what is the cause of the near panic that these reports have produced? Why are consumers so concerned? There have been a number of thoughtful articles on this topic; for example, a publication from the Dept. of Health, which points out that "Risks are generally more worrying if perceived:

- to he involuntary (e.g. exposure to pollution) rather than voluntary (e.g. smoking),
- as inequitably distributed,
- as inescapable by taking personal precautions,
- to arise from an unfamiliar or novel source,
- to arise from man-made rather than natural sources,
- to cause hidden and irreversible damage,
- to pose some particular danger to future generations,
- to threaten a form of death or illness/injury arousing particular dread,
- to damage identifiable rather than anonymous victims,
- to be poorly understood by science, as subject to contradictory statements from responsible sources"

GM soya scores ten out of eleven from the Department of Health fear factors. No wonder there has been trouble!

So, for reasons such as these, consumers want to make their own decisions rather than trust the experts. And what are the reasons for this loss of consumer confidence?

Let me suggest several:

- First, scientists, and the expert approval processes, are no longer trusted as they once were. The BSE epidemic has, of course, been disastrous for confidence.
- Second, I think the public is largely unaware of the development of careful scientific methods of assessing risk, such as the use of hazard analysis. But it is also true that we find great difficulty in explaining, and the public in understanding, what is meant by different degrees of risk, especially very low risk. Our National Lottery – with its slogan of "It could be you", does not help either – the message is clear: even what is very unlikely may happen. So even if the risk from a new product is very low, maybe it will be me!
- Third, the public finds it difficult to know how seriously to take the points put by the many single-issue pressure groups, a point I will return to later.
- Fourth, risks are assessed differently according to the context. We will accept quite high risks when we are seriously ill, but will not tolerate much risk at all with food. It is the latter that are causing the problems.

One explanation for such conflicting views is that scientists and the public work from different value systems. Scientists and technologists see novel applications of new discoveries as logical and reasonable – and characterise all opposition as unreasonable. "If only they understood what we are doing", they say, "the public would agree with us". Experience tells that this is not always true. Scientists and technologists are used to an uncertain world, where knowledge is always flawed, can handle risk judgements more easily, and are impatient of those who differ from them. The public's reaction is quite different, and it can be described as:

- Outrage – "how dare they do this to us?" – the way the public now regards Monsanto.
- Dread – the way we would regard a nuclear power station explosion.
- Stigma – the way the public regard food irradiation.

The net effect of this is that it is not possible to predict the way in which the public will react to a new risk by consulting just scientists and technologists. Social scientists, working in the risk perception area, can, in my experience, be of real assistance, but we need to consult further. My own view is that we are now going to have to evolve a new style for such decision making, opening up the process, but maintaining the input of the expert.

Why pick on GM soya?

Many of these issues crystallised over GM soya. Here was a product that offered the consumer some possible level of risk – none of us could absolutely rule it out – without any consumer benefit. Furthermore, it was being sold by a multinational, with headquarters in the US, who were out to make a profit at our expense. Finally, consumers lost the ability to choose, because the product was mixed with unmodified soya from the start. It will be a classic business school case of how not to introduce a new product for many years to come, but that does not help us right now, particularly in the face of the very professional public relations campaign that has been run by Greenpeace and the Friends of the Earth this last few months. Let me say a word or two about that.

The new public relations battle

We are getting very sensitive to talk of risk, particularly as other threats to our safety recede. Anthony Giddens, this year's Reith Lecturer, has made the distinction between 'natural risks', such as earthquakes, etc., and 'manufactured risk', which is due to our activity. I think that it is more complicated than this, and I would want to make a further distinction between those risks we choose to take and those that are thrust upon us, and yet a further one between risks linked to medicine and those linked to food. All this means that risk issues are not simple. But there is another factor too: the rise of the NGOs, who many consumers now feel to be their only unbiased champions. Is that really true?

Professor John Durant has pointed out that the Green Movement has been spoiling for a fight over agriculture for a long time and deliberately picked GM crops as its chosen battlefield. Indeed, a friendly member of Greenpeace told me in March 1997 that GM foods was going to be their next campaign, after Brent Spar and the Newbury by-pass. Friends of the Earth, Greenpeace and similar organisations have always been unhappy about the intensive nature of food production in the West, but have lacked a clearly defined target. Then along came GM foods – with their implications of insidious, invisible tinkering – and provided a perfect bulls-eye. The rest, as they say, is history.

What should we be doing about it?

First, and absolutely essential if this new technology is not to be killed in the UK, is a GM product with a consumer advantage. Then consumers will have a real choice, and they are good at such choices. Consumers were very quick to buy beef during the BSE scare when the price was halved; they reckoned that the reward was greater than the risk. Neither is it likely that mobile phones will be abandoned by users because of possible risk; they have too many advantages.

Second, we have to do all that we can to re-establish trust in the regulatory process. That certainly means continuing to open up the process so that it is as transparent as possible. Much has already been done, although often late and a mite grudgingly. All the Advisory Committees now have consumer representatives, and some have ethical advisors. Agendas, outcomes and advice to Ministers have been published for some time, and now Minutes are being displayed on the Net. Some Committees are experimenting in meeting in public. But I think we may have to do more, and work out processes that draw in the public at an early stage. For example, by drawing together, in a single decision making process, three different strands: scientific assessment of risk, public perception of this risk and the ethical issues involved.

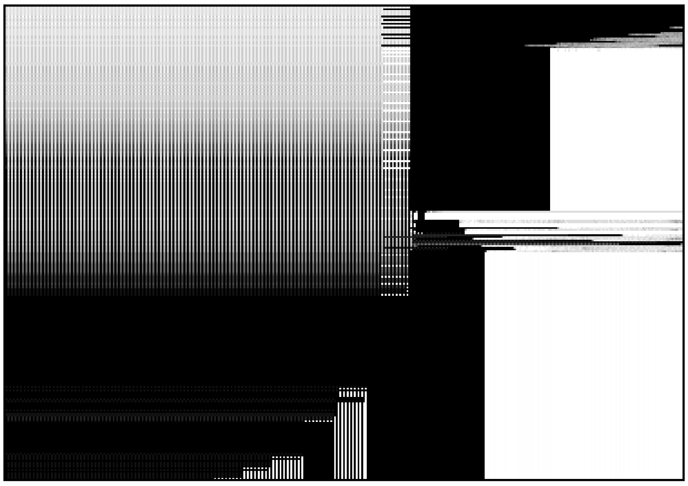
In such a forum there is a debate to be had about regulatory principles. For example, should risk/benefit analyses be used and if so in what way? There is much loose talk too about the 'precautionary principle'; but what does it mean and how could it be used without stopping all technology development in its tracks? Monitoring too is an active issue; how could that be accomplished at a reasonable cost and without excessive invasions of privacy? We already have had one row about the possible use of loyalty cards.

None of these options are cost free, while some of the other more radical proposals floating around – such as restricting GM crops to certain parts of the UK – could be extremely costly. Then what about the farmers; US farmers have embraced GM soya enthusiastically – clearly because it is their advantage to do so. But our farmers are going to have a harder time as the CAP is reformed and many will go out of business. Do we want to make it worse for them? Finally, do we want another issue over which to have a trade war with the US?

Third, we scientists are going to have to become much more professional about our response to the green groups and other NGOs. We have as scientists been increasingly active these last few years in explaining what science is about and what it can do for the public, and quite right too. Our problems start when we get drawn into the news; and it is obvious that Greenpeace and Friends of the Earth have completely controlled the agenda over the last few months. Every couple of days a new issue broke, and you and I were rung up by the *Today* programme, or one of its cousins, and were faced – and I have often been faced – with a series of dogmatic statements, none wholly true, and all with the same message: that GM foods are unsafe. Then there is what George Poste calls 'Paxman Redux'; "So you mean Professor, that you cannot guarantee that these foods are absolutely safe", or "So the British public is to be used as unsuspecting guinea-pigs again?" We are accustomed to debate, but this is no debate, and we find it very difficult to deal with black and white statements designed to stigmatise the technology. Look at what Lord Melchett, Chairman of Greenpeace, said to Lewis Wolpert on TV recently: "That's just twaddle", or the very recent over-the-top claims by Christian Aid in a report called 'Selling Suicide'.

I believe that our whole response has been too amateur. Who should respond to these outrageous claims? What role should OST play? What role could the Royal Society play? How can we draw in the large number of scientists with years of experience of regulation and of bringing products to market – none of whom are Fellows of the Royal Society? What role can the retailers and the companies and groups like the FDF play? Finally, what about Ministers? Splendid support from some, but others have been silent. Many of these issues are ultimately political, and if we don't get our act together we may lose this technology to the US. But the issues are wider than just GM, for they bear on the wider question of how our society uses science to create wealth. I suggest that we have stumbled, through GM crops, into one of the running issues for the next century. That is how do we balance personal, national and international needs in a world where all significant decisions are taken at the global level, and where the use of new technology will be on the main drivers of economic growth and also a major cause of public concern.

FOUNDATION NEWS



▲ *One of the Foundation's rapporteurs.*
Sir Geoffrey Chipperfield (right), one of the two who generously act as rapporteurs at the Foundation's evening seminars to provide the valuable neutral report of the discussions afterwards, in discussion with Sir Robin Ibbs, a member of the Foundation's Council.

▲ *Dr Monica Darnbrough discusses an issue with Sir Robert May at a recent event.*

NUCLEAR WASTE – PAST OR FUTURE?

The Foundation held a lecture and dinner discussion on the subject "Nuclear Waste – Past or Future?" at the Royal Society on 28 April 1999. The event was sponsored by BNFL and Synroc International Ltd and the Rt Hon The Lord Jenkin of Roding was in the chair. The speakers were The Lord Tombs, Chairman, House of Lords Select Committee on Science and Technology on the Management of Nuclear Waste, Mr Peter Beck, Associate Fellow, Royal Institute of International Affairs, and Professor John R Durant, Director of Science Communications, The Science Museum.

The Lord Tombs FREng*

Summary: Lord Tombs said existing nuclear waste management policy was fragmented and incomplete. He believed we should start as soon as possible on the task of public involvement and extension of our understanding of outstanding technical issues including those of monitoring and retrievability. Mr Beck discussed the possible world-wide future of nuclear energy within the energy scene of the next century and how this might affect the final disposal of nuclear waste. To resolve the many uncertainties that existed he suggested setting up three scenarios: one assuming phase-out of nuclear power, one continuation at about present levels and one based on expansion and transmutation.

The subject of management of nuclear waste was chosen by the House of Lords Select Committee on Science and Technology following the rejection of Nirex's planning application for the construction of a Rock Characterisation Facility at Longlands Farm, in Cumbria. Although some of the reasons for the rejection were environmental, the inspector and the technical assessor expressed some reservations about the geological issues and the level of understanding.

Since declared Government policy was for the disposal of ILW in a deep geological facility, this seemed to leave the policy in some disarray.

We considered the alternatives of indefinite surface storage and deep geological storage/disposal and rejected the former on the grounds of limited building life, involving building renewal and transfer of waste, and also the need for reliance on human supervision for millennia. We did not favour the necessary reliance on the stability of political and social systems over such timescales.

The widespread support at home and overseas for deep geological disposal, and the progress made in modelling and geological understanding, convinced us that this should be the method adopted. However, we recommend a system of "phased disposal" in which the waste materials would remain accessible and closely monitored until sufficient confidence existed to permit closure. Even after closure, retrievability would remain possible, albeit expensive and difficult.

In the course of the inquiry we recognised that existing nuclear waste management policy is fragmented and incomplete. Some materials for which no use can be foreseen are not categorised as waste and so do not enter into the calculations for disposal facilities. MOD have no disposal plans other than "wait and see". We recommended the establishment of a Nuclear Waste Disposal Commission with overall responsibility for disposal policy and with Parliamentary endorsement of policy renewed at regular intervals. We pointed out that more than one disposal facility may be required, depending upon the volumes to be accommodated and the rock bodies available.

The present stock of separated civil plutonium in the UK is about 60 tonnes and this is forecast to rise to well over 100 tonnes by 2010, representing two-thirds of the world's stock. This is a legacy of the past policy of fast reactors, for which there are no plans at present. The use of plutonium in MOX fuel will have little impact on stock levels. Large stocks of separated fissile material are internationally recognised as undesirable and trade in them is prohibited. We therefore recommended that excess plutonium stocks be declared as waste and treated accordingly. This has a substantial effect on disposed volumes.

We noted that studies of the environmental effects of reprocessing, as compared with direct disposal of spent fuel, were neutral within the limits of the parameters available. We also recognised that reprocessing has to continue for Magnox fuel and perhaps for AGR fuel. Beyond this, UK reprocessing is largely for overseas customers and while the German decision to cease reprocessing may be a straw in the wind other customers remain committed.

The acceptance by the public of the problem and of the need to arrive at a solution is an essential pre-requisite for the management of nuclear waste by any means and we pointed out that the legacy is with us now and is not affected in principle by decisions to cease nuclear power generation or to stop reprocessing. To gain public acceptance will be a long task and we envisage a period of at least 25 years will be necessary. We advocated widespread and open public consultation on the basis of a Government Green Paper leading to a White Paper and Act of Parliament. We consider it essential that policy is endorsed and renewed at intervals by Parliament. The timescales involved in the problem are unique in their length and the public fear of unseen radiation hazards combines to make this an unprecentedly difficult public policy issue. Public trust has to be built up by a process of open discussion and the use of novel consultation procedures and the consensus conference which will take place shortly, based on overseas experience, may be a useful pointer.

Finally, we emphasised that the long time scales involved are not a reason for delay. Rather,we should begin as soon as possible on the task of public involvement and extension of our understanding of outstanding technical issues including those of monitoring and retrievability.

Mr Peter Beck†

Introduction

I interpreted the title of this discussion as a question whether the main issue under debate is to deal with the waste of the past, or whether one must also look at the future, if any, of nuclear power and plan for the longer term disposal of waste. Rather than look-

** Chairman, House of Lords Select Committee on Science & Technology on the Management of Nuclear Waste*

† Associate Fellow, Royal Institute of International Affairs

ing at the UK scene in isolation, I shall, when discussing this question, consider:

(a) the possible world-wide future of nuclear energy within the energy scene of the next century;

(b) how this future might affect the final disposal of nuclear waste and then see how the conclusions from this analysis might affect the UK situation.

Energy in the next century

Forecasting such a time ahead is, of course, impossible and a waste of effort if attempted. However, one can usefully study the future via use of scenarios – looking at widely different futures, but all within bounds of possibility – and thereby achieve an understanding of the forces – technological, economic, social, political – which will mould the energy scene of the next century. The scenarios used for this talk were developed in 1995 by the World Energy Council and the International Institute for Applied Systems Analysis (IIASA), both respected bodies and neutral in the pro- and anti-nuclear battle.

For our purpose, there are five strong messages from these scenarios:

I. The level of future energy demand is very uncertain – by 2100 between 2½ and 5 times the 1990 figure of some 9 Gtoe. Because of more recent work on population growth which showed very wide ranges of possibilities, future scenarios may well increase that range.

II. If, on the supply side, one excludes the issue of climate change and, therefore, any thought of having to limit CO_2 emissions, there should be plenty of fossil fuel resources for the next century. There is no strong case for nuclear power to be essential, unless it becomes more economic than fossil fuels.

III. If limitation of CO_2 is assumed, there are presently two very strongly held views: One, held by the nuclear industry and its supporters, is quite certain that there will be a definite need for nuclear power during the next century. The other, supported by environmentalists, suggests the opposite. There will be no need for nuclear energy: increases in energy efficiency plus rapid growth of renewables can fill any energy gap left by limiting use of fossil fuel.

Both sides are certain of their position and are contemptuous of the opposition. A more neutral analysis, however, shows that both views are within the realms of possibilities and that with today's knowledge it is impossible to tell who is right, if either.

IV. Bearing in mind the uncertainties on both the supply and demand side of the future energy scene and that the strategic answer to uncertainty is flexibility, there is a good case for keeping all options, which could produce significant amounts of energy without increasing CO_2 emission, open. That would include nuclear energy, indeed, the only option which is already delivering some 7% of primary energy. This option should be kept alive until more is known about renewables and improvements in energy efficiency, possibly for 15 to 20 years.

V. The industry is greatly disadvantaged by its unpopularity. Unless that is changed its future may well be bleak.

Keeping the nuclear option open

But what does 'keeping the nuclear option' mean? It implies that the world should be in a position in *x* years time to make the choice whether or not to expand nuclear energy to become a significant energy source by a chosen time during the next century. To achieve this, nuclear energy must be able and be seen to be able to overcome present public concerns, which include the dangers of weapons proliferation and the lack of acceptable solutions for nuclear waste.

One also has to define 'significant'. It is suggested that unless today's 7% of demand can increase to perhaps 15-20% by 2100, there must be doubt whether the additional flexibility achieved through keeping the nuclear option will be worth the effort. That implies a capacity of 3500 to 5000 GWe by the end of the next century, compared to some 360 GWe today. But is today's technology really adequate for such an expansion to be acceptable by the public? I believe not.

Without reprocessing, spent fuel would have to be classified as high level waste (HLW), as is the case in the USA today. Assuming no uranium resource constraints, or use of thorium, that would mean more than 60,000 t/yr (heavy metal) of spent fuel made by the second half of the century, or close to one new Yucca Mountain size repository per year. Bearing in mind the complexity, unpopularity and cost of repositories*, such a plan is hardly feasible.

With reprocessing and the use of fast breeders in the second half of the century, there would be many reprocessing facilities spread over the globe and a vast number of shipments between reactors, reprocessing and fresh fuel manufacturing plants. Many of the materials shipped would contain plutonium without being safeguarded by strong radioactivity. When such a system was studied in the USA† during the 1970s concern was expressed that it would increase the dangers of weapons proliferation and that was one of the reasons why the USA decided against reprocessing and is still strongly opposed to it. As little has changed in this area, there has to be doubt whether nuclear expansion based on what is termed 'the plutonium economy' would be acceptable to the world community. At the very least it would provide excellent ammunition for the anti-nuclear lobbies.

The research community seems to have accepted that resolution of the waste issue is vital to the survival of nuclear power and that the means thought appropriate for dealing with spent fuel in the 70s are no longer adequate. They are working in the USA, Japan, Russia and France to provide alternative solutions which would ensure proliferation resistance of the processes and be more acceptable to the public.

Much of this work is based on the concept of transmutation, whereby all trans-uranic elements and some other long-lived fission products are separated from spent fuel and other high and intermediate waste and 'transmuted' by being bombarded by neutrons into less long-lived elements in either fast reactors or accelerator-driven sub-critical systems. The heat produced in the reactions would be utilised for power production. In this system the final fission products would still have to be sent to repositories, but the quantities might only be some 5% of spent fuel, they would contain no material of use for weapons and the radio-toxicity of the final waste should, after some 400 years, be less than that of spent fuel after 100,000 years. The purpose of the work is to reduce the volume needing long-term secure storage and to ensure no chance of proliferation. This latter would be achieved by the transmutation and partitioning being carried out on one site: the site would receive spent fuel and other HLW, export electric power, uranium for further use or disposal and a relatively small quantity of final waste to a repository.

The work is only in the research stage and there can be no guarantee of success. To develop such a system beyond pilot-scale and up to the point of preliminary design for a commercial scale prototype may take ten to fifteen years and may cost up to $1 bn. But, if successful, it would not only reduce the number of repositories needed, each at costs of well above $1 bn, but it might well make public acceptance of nuclear power easier. Indeed, without this or a similar development, one has to wonder whether nuclear energy can have a future.

In summary

- Keeping the option implies making major expansion of nuclear power an economic, technological and political possibility. There are doubts whether today's technology would be able to achieve this.

** Recent cost estimates by the US DoE shows the cost of the Yucca Mountain project up to the year 2116, when final closure is due to take place, to be $43.7 bn. Estimates for the Pangea project in Australia are $6bn capital and $450 million/year operating costs.*

† Report of the Nuclear Energy Study Group, Keeny S.M., Chairman 1977: Nuclear Power Issues and Choices, *Ballinger, Cambridge Ma.*

- Indications from research show that a more acceptable fuel cycle could be developed, but this would require substantial time and funds to develop. We have the time, but much of the funding will have to come from governments. Without such R&D, the industry is likely to die. The anti-nuclear lobbies are aware of that and are, therefore, likely to mount a campaign against such expenditure, arguing plausibly from their point of view that money would be better spent on a more rapid development of renewables and on improving energy efficiency. The task of convincing governments to fund such work will, therefore, be difficult, unless public aversion to nuclear power can be reduced.
- The most important conclusion is the need to take action on unpopularity. Instead of being on the defensive and argue that the public is misled, the industry has to accept the public's concerns and show that it is doing something about them. But, please, not via a P.R. campaign showing green fields, cows grazing and firm statements that "all is for the best in this, the best possible world".

The UK situation: the past or future?

In the light of the above, it is clear that I greatly welcome the insistence of the House of Lords Select Committee's Report of having to achieve public acceptance of any national plan for the management of nuclear waste, as well as the need for openness and transparency in decision making. I also welcome the acceptance that there is no rush to complete a repository. I can see no reason for hurrying; intermediate storage will be needed in any case and that will have to give us time to sort out the technology, economics and politics of final storage. The Report is, surely, also right in suggesting that this sorting out should start soon, if only because it might take longer than we think.

There is one criticism. The Report seems to be dealing with the past and present: it does not deal with the future of nuclear energy in this country, but the implication is that nuclear power will be slowly phased out. If the option to keep or even expand nuclear energy during the next century is to be kept open, the question has to be asked whether this would change the strategy for nuclear waste management? The answer may well be 'no', but the question should be asked. I cannot see how one can achieve public acceptance of a plan for waste if there is no information about the future generation of waste.

It should not be too difficult to set up, say, three scenarios for waste management in the next century – one assuming phase-out of nuclear power, one continuation at about present levels and one based on expansion and transmutation. It would then be possible to see what effect these different assumptions would have on waste management and the choice of repositories. If one considers cases which may take 40 or 50 years to come to fruition, surely such a long-term look is necessary. By the time firm decisions about major investment need to be taken, far more should be known about which scenario to follow. That does assume that we shall have adequate safe and secure interim storage available until permanent facilities become operational. As the Report mentions, that may well be as long as fifty years.

There is the question whether deep repositories are the right answer. As I see it, the only alternative is surface or shallow storage, which would always be accessible. That's fine for fifty or even a hundred years, but surely not for thousands of years. So, if one rules out disposal in deep ocean or into space, I can't see an alternative to deep repositories. But, let us bury the minimum amount possible in them.

Lastly, there is the matter of the definition of waste. Fig. 1 in the Report uses the official definition for waste, which, as I understand it, defines high level waste *inter alia* as those materials deemed by HMG to be high-level waste. As mentioned in the Report, stocks of plutonium and of some unreprocessed spent fuel are not included because, for now, these materials are considered to be a potential resource. To some degree such a definition is close to Humpty Dumpty's definition of words: 'When I choose a word, it means just what I choose it to mean. One would have thought that issues of safety and security would indicate the definition should be the other way round – that any stream for which there are no firm plans should be considered as waste. Certainly, a revision of the present definition, as proposed by the Report, is essential!

LINKING SCIENCE AND INDUSTRY

The Foundation held a lecture and dinner discussion at the Royal Society on "Linking Science and Industry – improving the dialogue on risk assessment between the insurance sector and the UK science base". The event was held on 13 April 1999 and was sponsored by the TSUNAMI Consortium: Benfield Greig Group, Catlin Underwriting Agencies Ltd, CGU Group, D P Mann Ltd, Royal & Sun Alliance Insurance Group plc, Sedgwick Reinsurance Brokers, Wren Syndicates Management Ltd and the DTI's Sector Challenge. The Rt Hon The Lord Jenkin of Roding was in the chair and the speakers were Mr Steve Robson CB, Second Permanent Secretary, HM Treasury, and Director, Finance, Regulations & Industry Directorate, Mr Nick Golden, Director, Underwriting, Reinsurance & Risk Management, Royal & Sun Alliance Insurance Group plc, and Professor Julian Hunt CB FRS, Department of Applied Mathematics & Theoretical Physics, University of Cambridge.

Summary: The following paper formed the topic for the evening's lectures and discussion.

The TSUNAMI Initiative – linking insurance and science

TSUNAMI is a three-year initiative, established as a joint venture between the UK government, the UK insurance industry and the UK scientific community, to foster collaboration and the use of applied scientific research to improve competitiveness.

Change agents for industry and science

Before creation comes change; nothing can be achieved without change.

We live against a background of change. Nature, society and economics are constantly changing. The UK, like other countries, faces the challenge of responding to change, to protect or transform existing interests and to seize the opportunities that it presents. Globalisation of trade and commerce make the impact of change more immediate and increases the pressure on countries to invest in their own proficiencies and in new technologies.

Recognising this, the UK Government established the Foresight

Programme in 1994, with the aim of improving the UK's competitiveness and enhancing the quality of life, by bringing together business, science and government to identify and respond to emerging opportunities in markets and technologies. Foresight inspired the creation of the TSUNAMI initiative.

TSUNAMI aims to improve the competitiveness of the UK insurance industry by using the UK science base to improve the assessment of risk. TSUNAMI was established in September 1997, with funding from the DTI's Sector Challenge and a consortium of companies from the UK insurance industry. Dr Dougal Goodman, Deputy Director for Innovation at the British Antarctic Survey, developed TSUNAMI as a concept and secured the initial commitment from the DTI and the industry sponsors. He also chairs the Management Board.

In December 1998, the Government published its Competitiveness White Paper, describing "The Knowledge Driven Economy". TSUNAMI shows how this vision might be achieved. Day to day, TSUNAMI promotes, develops and delivers scientific research within the insurance industry. However, its longer-term aims are in effecting cultural change within science and industry. These changes are essential to ensure the continued effectiveness of both communities and, ultimately, to create wealth.

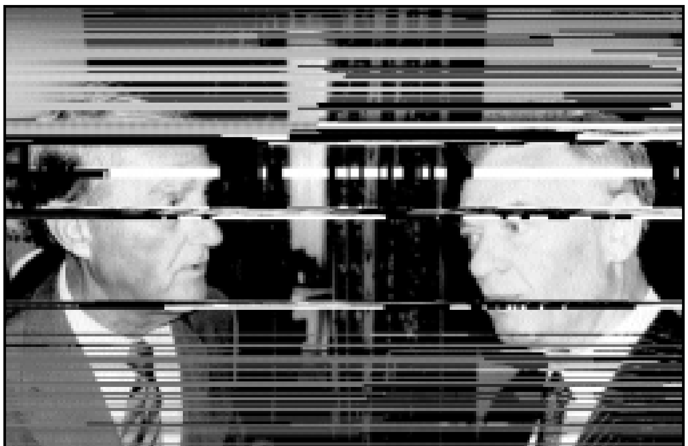
Risk management

Risk management involves the identification, quantification, mitigation (reduction), transferral (eg through insurance) and retention of risks. Through good risk management, businesses and government can avoid the mis-allocation, less and misuse of capital and resources. This will ultimately lead to improved effectiveness and efficiency which are crucial factors in driving competitiveness.

However, risk management is often perceived as costly in both time and money. It is most relevant at the planning stage of activities (say, in building a road), before the benefits and return from an investment become apparent. There are numerous cultural barriers to supporting this investment to gain "foresight", which deny the benefits from identifying new opportunities and threats.

Many organisations believe, correctly, that they are best placed to understand their environment and, incorrectly, that they are best placed to deal with changes in that environment. There is also a tendency to wait until the pressure from these changes is so immediate that it cannot be ignored, particularly where similar risks have not been seen before or there is a belief that the risk cannot be managed.

In recent years there has been an expansion in the remit of risk management, to include traditionally uninsurable and unquantifiable risks. Such risks include "reputation" risks, where the value of a company or government agency (in the market's or the public's eyes) might suffer as a result of an incident that brought their effectiveness into question. Reactive responses to such crises have often proved inadequate and organisations are increasingly looking to recognise, reduce and plan for all risks.



▲ *Mr Stuart Mustow (left), Chairman of the Hazards Forum, and Vice-President of the Royal Academy of Engineering, talks with Sir Frederick Crawford, Chairman, Criminal Cases Review Commission, and past Vice-Chancellor of the University of Aston, at the event.*

Many organisations are now adopting the mind-set that they can manage all the risks they face. It is fair to say that public beliefs and expectations have preceded this development by a number of years, as evidenced by recent scares in the food industry. As few organisations are equipped with the knowledge and expertise to understand and develop solutions for all the risks they face, they need to look to external expertise.

External expertise

However, to ask an external expert for help, either you have to fully understand your circumstances and the nature of your problem (eg asking a local citizen for directions when driving in a new town) or the expert must have that knowledge (eg when visiting your doctor). Without this prior knowledge, a process of consultation and dialogue is essential.

The experience of TSUNAMI has shown that facilitation between the expert and the "user" to identify users' requirements is essential. Both sides are often too busy, with their core activities, to take time to understand the other side. Language and motivation contrast strongly with market terms and financial gains bearing little comparison to scientific expressions and breakthroughs in knowledge.

Facilitation is a key role for the initiative, which has created substantial networks within the scientific and insurance worlds. New technologies, such as e-mail and the Internet, have helped support these networks, although face-to-face contact still remains the cost effective, if costly, means of communication.

TSUNAMI has run a number of workshops for staff from the insurance industry to listen to scientists talk about their work and to discuss its business relevance. This helps to raise awareness of scientific research within industry and to develop an understanding of how research can be shaped to boost competitiveness. However, there is rarely a simple solution to risk assessment problems, as data is not always available to answer all of the questions that are asked.

To analyse risk, data is essential, either on past incidents (in this case, insurance claims) or on its constituent elements (hazard, exposure and vulnerability). However, to support their operations, companies typically use data that is not ideally configured or preserved to support risk analysis. This can be frustrating for scientists, but the facilitation process can help them to understand the reasons for this and explain the consequences, for the quality of the analysis, to the companies.

Also, to be truly effective, risk assessment needs to move from a one-off, ad hoc, process to one of constant monitoring. To do this, risk management needs to be integrated within business. It needs to guide the strategy of companies and to contribute to the debate on the key aims of an organisation. Moreover, there needs to be explicit consideration and recognition by companies of what level of risk is acceptable, as ultimately some risks will be retained by the business.

Risk

Risk can be usefully defined as "loss, the occurrence of which is uncertain". Risk has three essential elements:

- hazard (eg a flood) that might cause a loss;
- exposure to loss (e.g the value of a house, or its contents), and
- vulnerability of that exposure to the hazard (eg a metre of water might destroy all the carpets and all the possessions on the ground floor of a house).

Without each of these three elements, there would be no risk. Also, there must be uncertainty within at least one of the three elements for a risk to exist. For instance, holding a five-pound note in the flame of a match has no risk, as the hazard, exposure and vulnerability are all certain.

TSUNAMI's initial funding of £960,000, to be spent over three years, has been largely committed to research into natural hazards, including:

- forecasting tropical cyclones (hurricanes and typhoons) which threaten the US, Caribbean, Japan and Australia;
- forecasting extreme weather (windstorms, heavy rain, drought and freezing) affecting Northern Europe; and
- assessing earthquake risks for the world's major cities.

Changing risks

We began by discussing change. New technologies present new risks, as evidenced by the "Millennium Bug". Also, increases in wealth and population levels will increase the "exposure" and often the "vulnerability" elements of risk. This can be seen in the expansion of residential areas in Florida, which is prone to hurricanes, and in the need for new housing developments in the UK. Also, modern households have an increasing number of high value, high vulnerability goods, such as hi-fis and personal computers.

One of TSUNAMI's funded projects seeks to address the challenge presented by changing risk from flooding in the UK. Households in the UK have universal access to flood insurance protection. However, with the demand for new housing, it is possible that pressures on planners and inadequacies in building standards will lead to more vulnerable houses being built in more hazardous areas (eg in flood plains).

With the potential for increased precipitation from the effects of global warming, the risk that insurers accept in providing good insurance may increase beyond an economically supportable level, with homeowners being unable to afford the higher insurance premiums.

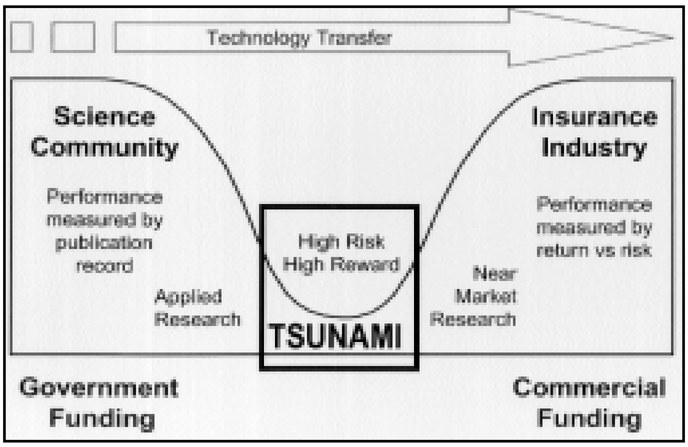
The TSUNAMI "UK Flood Risks Project" seeks to consider the issues that face insurers in providing protection against flood risks, the potential options that are available and their consequences. The research process will include consultation within the industry and with Government agencies to inform strategy in this crucial area for the UK economy.

More generally, insurers can no longer rely on the past as a guide to the future. Changes in either of the three key risk elements are increasingly likely and they need to be careful about how they use the past to guide current and future decisions. Logical, scientifically based structures for analysing risk and decisions can help companies blend their own experience, data and external information to arrive at the best decisions for them.

Boosting insurance industry competitiveness

One of the challenges TSUNAMI faces in promoting scientific research within industry is in bridging the "valuation gap" between what scientists and insurers think research is worth. Industry assesses value through impacts on profitability. Quick results are more readily seen as being successful and therefore represent less risk. Scientists value research on the opinions of their peers and it often comes from long-term, thoughtful analysis.

However, perceptions are changing, through increasing financial exploitation of intellectual property (eg patents and copyright) within science. Also, many within industry recognise the need to invest in research and the longer term to protect their future. Technology has reduced the importance of the transactional aspects of financial services and the need to demonstrate the value added by service to clients and customers is crucial to continued survival.



Also, for the insurance industry, other financial services sectors are able to offer insurance products and there is a blurring of the divide between markets. New, bigger players have entered the market, with a consequent increase in competition. Risk management itself has given many customers control over their own risks and reduced the need for insurance expertise and cover.

To rise to this challenge, from the UK and outside, the UK insurance industry needs to give a collective response. Part of TSUNAMI's mission is to pull together leading players from the composite insurance, broking and Lloyd's markets to share experiences and views.

Alliances are increasingly important within business. The ability to work with partners, to respond to a threat or seize an opportunity, can determine the success or failure of an organisation. Within an industrial sector, the need to "collaborate to compete" is seen by the Government as essential to the UK economic health, as described in the Competitiveness White Paper.

A particularly important issue for insurers is what they do with the results of research. Decision making structures within most organisations are built to handle existing information generated by the business. New information, on a new challenge or issue, requires careful consideration and dissemination. Otherwise, its impact will be minimal. This is where cultural change is most needed and a lot of work will need to be done for companies to appreciate the options available to them in responding to new information and in ensuring that the greatest value is achieved.

Finally, a point that increasingly concerns companies is "how do we differentiate ourselves in a commoditised market?" Companies need to innovate to give new products and services to customers. The quality of service must increase, despite constant competitive pressure on prices.

To achieve this, companies need to get closer to their clients, concentrate on what they need and what will make them choose one supplier above another. Looking outside to external experts to solve their own business problems can teach companies how to become solution providers for their clients. In the knowledge driven economy, this proficiency will be mandatory.

Realising science's commercial potential

The challenge in science is to foster and respond to the demand from industry for help and new ideas.

Existing structures support research through assessment by peers, to rank proposals and the results of research projects. This system penalises research across disciplines, as reviewers must focus on the elements that they know best. The result is that a proposal's value is reduced if it includes elements from an outside discipline. Similar valuation problems arise in the assessment of research capabilities of university departments. This issue must be addressed if the UK research communities' commercial potential is to be realised.

The next challenge is in managing intellectual property rights (IPR), which often present the means by which commercial value can be realised, through licence agreements and patents. Proficiency in managing IPR needs to be built up within the science community, by sharing experiences, training and best practice.

Government has a key role to play in this process. Funding from industry may present great opportunities for growth for the support of future research, but commercial funding cannot be relied on at all times. The challenge of mixing public and private funding of research cannot be overstated. TSUNAMI, in working with researchers, is giving scientists a taste of what it is like to work with industrial sponsors. As well as tailoring original research proposals to match sponsor's needs, revisions are often needed as needs change with developments in the market.

TSUNAMI has also shown that research results will not define the response of companies, but it will be an additional influence. The extent of that influence will rise with increasing credibility and trust. Science needs to work at raising its credibility within industry, by maintaining a sustained profile and by explaining the value and implications of its research, both of which TSUNAMI seeks to achieve.

With improving risk management and increasingly capital-rich organisations, the focus of insurance and reinsurance (the “insurance” of insurance companies) has turned to extreme events, which might jeopardise profits or the continued solvency of an organisation. The prediction of low probability, high severity events is key to this area. However, by definition, there is little data available on past “catastrophes”.

TSUNAMI has supported a programme at the Isaac Newton Institute for the Mathematical Sciences, which developed statistical tools to make optimal use of data on extreme events. “Extreme value statistics” has undergone a revolution in recent years, with improvements in computing power and, working with technical analysts from the insurance industry, it is working to translate these tools for use in insurance.

The potential also exists to make increasing use of weather and climate forecasts, to not only assess insurance risks, but to consider the implications for health and energy consumption. This will be a growth area for industry and the insurance industry in particular. TSUNAMI is also active in this area and will help the UK insurance industry in rising to this opportunity.

Laying the educational foundations

Finally, a few words about the foundations in education that need to be laid to ensure a bright future for the UK financial services sector.

Sustainable growth and high employment may be achievable through the information age, but it will not be solely due to hardware and software. People need to be equipped to effectively assimilate and disseminate information accurately and creatively. Speed in recognising and seizing opportunities is currently essential in the commodities and derivatives market in investments, but may increasingly make the difference in insurance.

To realise potential, teamwork is often essential. Recent breakthroughs in science have often involved large teams of researchers, working together in sophisticated areas of technology, but also achieving a creative synergy through their interaction. This challenge also faces industry and the ability to work with others will be a key proficiency for the future. Also, as new economies grow, skill in understanding other languages and cultures will be essential to support business with those new clients and customers.

Technological literacy, numeracy and a grasp of logic will be entry tickets for many of tomorrow’s industries, especially insurance. Again, to meet this challenge, the insurance industry will have to look outside for help. The ability to hold an effective discussion of their “users’ requirements” with educational experts will be essential to success.

HOW INTERDISCIPLINARY IS THE SCIENCE BASE?

The Foundation held a lecture and dinner discussion with the subject “How Interdisciplinary is the Science Base?” on 30 March 1999 at the Royal Society. The event was sponsored by AstraZeneca plc and the Rt Hon The Lord Jenkin of Roding was in the chair. The speakers were the Earl of Selborne KBE FRS, President, Parliamentary & Scientific Committee, and Vice-President, Foundation for Science and Technology, Professor Burton Richter, Director, Stanford Linear Accelerator, USA, and Professor Julia M Goodfellow, Department of Crystallography, Birkbeck College.

The Earl of Selborne KBE FRS*

Summary: Lord Selborne examined the present system for selecting and funding science and technology research *vis à vis* the 1993 White Paper “Realising our Potential” and the Foresight programme. In particular, he examined the issues of funding and determining what should be deemed ‘relevant’ research. Professor Richter gave examples of the interdisciplinary nature of research, quoting examples of work that had benefited areas other than those for which the work had originally been done. He also discussed the problems of funding.

Introduction

I offer my thoughts on the interdisciplinary nature of our science base from the perspective of a user of research. I hesitate to call myself an industrialist as this seems a rather misleading name for an apple grower. My contribution is focused on our science base in the United Kingdom and I have no doubt that others will look farther afield. We need first to remind ourselves of the case for funding science and technology. We need then also to consider whether the present system for selecting research priorities, for determining the funding level, for managing, monitoring, assessing and accounting for this research all delivers what society is expecting for its money.

“Realising our potential”

These were in essence the issues addressed in 1993 by the science, technology and engineering White Paper “Realising our Potential”. The central thesis of this paper was that science and technology can and must contribute to national prosperity and the quality of life. For this we need a strong pre-competitive base working in areas of importance for the nation. The critical issue is how and who decides what areas might be deemed of importance to the nation. To help determine this the White Paper proposed the development of partnerships of scientists, industry, policy makers, commerce and others particularly through Technology Foresight. The public and private sectors would therefore be more closely integrated and the concept of relevance in determining areas of research would be more strongly emphasised. We recognised that no longer could the United Kingdom compete in “me-too” research.

Technology Foresight, now Foresight, has been widely admired and followed around the world. It has been the process as much as the product which has proved its worth. There was concern at the time that the increased influence of industry might lead to a greater emphasis on short term research. As I had been a lay chairman of a research council I did not accept this thesis at the time,

** President, Parliamentary & Scientific Committee, and Vice-President, Foundation for Science & Technolgy*

and I believe events have proved that these fears were misconceived. Industry has demonstrated that it looks to the science base to provide the fundamental, underpinning research which cannot be provided from the private sector.

What is 'relevant'?

The issue of what should be deemed "relevant" proved more problematical. This criterion was qualified in the White Paper:

"While research quality should not be compromised increased attention must be given to the relevance of research outputs to users in the industry, commerce and the government. In particular research should be directed to wealth creation and improved quality of life".

All this may seem perfectly reasonable, but it raised a number of issues. It was an expedient statement if the object was to persuade government and taxpayers that the science base was to be more directly accountable for its public funds. This was an important consideration after many years of declining funding. The need, therefore, to demonstrate relevance as well as quality was driven by the need to improve accountability. However, a research programme might sometimes not prove its relevance until years later. Research quality might still prove more appropriate criteria for support than perceived relevance, given the nature of fundamental research.

New structures were proposed in the White Paper for administering research programmes. These structures were designed to widen consultation and improve the evaluation procedures. Broad programme areas were established within each of the six research councils' remits. Again there was concern at the time that the occasional maverick who worked outside these programme areas and was not following the perceived wisdom might never again prove his or her worth. While it is easy to put undue confidence in the individual scientist who is now a very rare phenomenon, I still believe that it is reasonable to hope that we will continue to fund the occasional science project which is outside the main stream of conventional wisdom.

The egalitarian in funding

I suspect that we have been too even-handed and egalitarian in distributing our research funding. We have opened up the markets for research contracts too widely, spreading resources too thinly. Perhaps this is the consequence of widening consultation. On the evening of the Second Reading in the House of Lords of the bill to remove hereditary peers from parliament you will not be surprised that I, a hereditary peer, am still fighting for that unfashionable cause of elitism. I caution against too much democracy. If research quality is to be the basic criterion for the determination of research funding then we must ensure that we have an appropriate research infrastructure in place. We cannot provide this infrastructure in each and every one of our universities. There must be partnerships between universities and there must be recognition that weak universities and weak departments should be allowed to go to the wall.

▲ *Professor Burton Richter, right, talking to Professor Ian Halliday, Chief Executive, PPARC.*

We must be flexible enough to fund rising stars, but this does not mean that we can continue to expand our research infrastructure. When I chaired the Agricultural and Food Research Council we were faced with too many institutes on too many sites, many of which were remote from universities. We closed a number of sites, concentrated facilities and developed synergies. I look now with some pride at the reduced number of sites which are of international excellence by any standards. For example, the John Innes Institute joined with the Cambridge Laboratory and the Sainsbury Laboratory at the University of East Anglia, and the result has been a spectacular success in capturing the benefits of collaboration. Another example I would quote is the Institute of Animal Health at Compton, not a university site but where the concentration of resources has enabled a first class infrastructure to deliver first class research. The recent establishment of the Joint Infrastructure Fund by the government and the Wellcome Trust is a very desirable innovation. However, even if this fund could be expanded it will never provide the infrastructure resources that will be demanded and we must recognise that harsh decisions must be made as to how we focus these resources.

Technology transfer

Another thrust of the White Paper was the emphasis on the need to improve technology transfer. This is a familiar refrain. Our national competitive status would be enhanced, it is claimed, by improving our technology transfer. The result has been that all universities seem to be in the business of developing their innovation strategies. A cluster of high technology companies around a university is seen as a stimulus to increase research funding and as a potential income stream by exploiting university-owned intellectual property rights.

Dr Alan Rudge, Chairman of EPSRC, has called this "invention mania" and has cautioned the science community not to fall into the trap of being judged on the value of its inventions and prizes. He pointed out that any clear-headed businessman would soon conclude that when the cost of the science base is balanced against the value of these products the bargain is seen to be a bad deal. However, there are two core products expected from the science base: firstly, an expansion of our knowledge base, and, secondly, a stream of scientists with relevant expertise. While an extra income stream would be welcome it is not the main product that taxpayers are expecting, and there is a danger that by giving too great an emphasis to exploitation of intellectual property rights the research programme might be distorted away from its main purpose.

Has this increased accountability and the need to consult widely, as well as to monitor and assess results, helped us or hindered us to allocate our resources more effectively? In the words of the White Paper can we now provide research of the highest quality and relevance to users in government, industry and commerce?

I wonder whether we have gone too far in following conventional business school advice. For example, the chief executives of the research councils are on relatively short-term contracts, and they seem to have a considerable element of performance-related pay. This does not seem to me to accord very happily with the concept of developing long-term research. There is an obsession within the head offices of most of the research councils about reducing their costs. This can be counter-productive when trying to add value to research at the laboratory bench.

Success of consultation and interaction

However, I do believe that consultation and interaction provided by Foresight has been a success. The amount of monitoring and evaluation of research programmes seems to be increasing and this is exemplified at its worst by the European Union Framework Programmes, which are hopelessly bureaucratic. The amount of monitoring and accountability is not effective, and is certainly not adding value in any sense whatsoever. Our Research Assessment

Exercise was probably effective the first and second time around, but I wonder if it is now becoming less so. I would agree with Sir Derek Roberts that we should freeze the current RAE ratings for 10 years. I recognise that this might be frustrating for those who are trying to bring us the standards of a department. However, this would encourage research with a longer time horizon than that which merely meets the requirements of the next scheduled Research Assessment Exercise and would, therefore, prove another blow against short-termism. There is a danger at present that the Research Assessment Exercise does not foster interdisciplinary or inter-university collaboration as the unit of assessment has to be placed one side of the fence, precisely contrary to the spirit of encouraging collaboration.

Interface between disciplines

If I were to speculate on the future most productive areas of science I would suggest that we might be looking at the interface between disciplines. For the last decade or more we have seen an enormous expenditure and investment in gene mapping and genome sequencing. There will come a time when gene mappers will have done their task and we will need to move on to find out how genes work, and how the whole genome comes together to function as it does. Structural biology on its own clearly has its limitation. We will be looking to physiologists, mathematicians and material sciences as well as many others to make their contributions.

Conclusions

In summary, the White Paper was right to stress the role of science in wealth creation and enhancing the quality of life. This White Paper has proved helpful to those who have fought successfully in recent years for the cause of stabilising and ultimately increasing the funding of the science base. Scientists also need to be reminded to whom they are ultimately accountable. But if we want a science base that can react rapidly to the opportunities offered by science itself and to society's changing requirements, then let us not follow too rigorously each fashionable business school nostrum.

Perhaps at the end of the day excellence in science remains the only certain criterion for determining whether research funding is appropriate.

Professor Burton Richter*

Introduction

My perspective is that of a physicist who has done research in the university, has directed a large laboratory involved in a broad spectrum of science and technology development, has been involved with industries large and small, and has some experience of the interaction of science, government and industry. From that perspective I, as would most scientists, greet the question that is the topic of this forum with some degree of suspicion. There is most likely something behind it more than an innocent inquiry, and that "something" probably has to do with making science more productive.

Investment in the UK

The British Government is increasing its investment in science, and, like most investors, would like the greatest possible return for its funds. If I have the correct numbers, British Government funding for science is to increase in real terms by nearly 15% over the next three years, and the Wellcome Trust plans to contribute an additional 400 million pounds. The Government's investment is indeed a departure from recent practice and therefore is cheered by the science community. To put it in perspective, if the 5% per year increase is continued for the long term, science funding would double in about 14 years. Since the British economy is growing at about 3% per year, a 5% increase in science funding would double science's share of the economy in 36 years. Since high-tech industry represents an increasing share of every economy, including Britain's, and science is the fuel on which high-tech industry operates, the news is good, but not spectacularly so.

Where to target the investment?

Among the stated goals of the increased Government investment in science is creating prosperity, reducing the cost of ameliorating certain societal problems (medical, social, environmental, etc.) and improving the quality of life. These are indeed worthy goals, but the question remains: where should the new investment be targeted? If science were a tame beast that would hunt as it was told, it would be much easier for governments to decide on areas of investment. However, science is not like that. When sent out to hunt foxes, it sometimes brings back foxes, but sometimes it brings back unicorns. The foxes add to our understanding; the unicorns transform it. For example, Max Planck, in 1901, gave us the quantum hypothesis as a solution to a very troubling problem in classical physics: the spectrum of light emitted from a hot body. That transformed all of science and is the rock on which modern physics, chemistry and biology stand. More recently, in the early 1960s, Charles Townes and Arthur Schawlow gave us the laser. They had no idea of the breadth of application that the laser would have: today it is the heart of the communications revolution where pulses of light travelling through hair-thin pieces of glass replace electrons travelling through copper wire, and, by the way, also cut metals, perform surgery, etc.

Governments, in building their research portfolios, must remember the time scale from basic research to the products that affect society. From Max Planck to the transistor took nearly 50 years. From Townes and Schalow to optical communication took 30 years. From the recombinant DNA work of Cohen and Boyer to today's biotechnology industry took 25 years. If government investment targets only areas that can be expected to pay off in a short time, the science beast will bring back no unicorns and only scrawny foxes.

US data

There is good data in the United States showing that federal support of research has paid off. A recent publication from the Brookings Institution and The American Enterprise Institute looks at the impact of R&D on the economy. The study shows that about 50% of the economic growth in our society come from the introduction of new technologies. A study commissioned by the National Science Foundation shows where the new technologies come from. Patent applications in the United States are supposed to cite the "prior art" on which the particular patent is based. The NSF study shows that 73% of the "prior art" cited in patent applications from US industry comes from publicly funded research. These two studies taken together indicate that government investment in long-term scientific research is very good for society.

Interdisciplinary nature of the science base

There are many modes of interaction between scientific disciplines, and I look first from the perspective of how one area of science enables other areas. I choose, for an example, one that might appear at first glance to be the least likely field to enable others – high-energy physics and accelerator technology. In 1970, I began building a device called a colliding-beam storage ring to do the research in high-energy physics that won for me the 1976 Nobel Prize in Physics. When the accelerator was nearly complete in 1972, four people came to me asking for a small modification in the machine that turned out to have had a revolutionary impact on many fields of science.

The four were a materials scientist, an electrical engineer, an applied physicist and an accelerator physicist. The modification was a change that would let out of the machine the intense x-ray

* *Director, Stanford Linear Accelerator, USA*

beams that were produced by the stored electrons in the machine. The SPEAR Storage Ring at the Stanford Linear Accelerator Center became the first of the modern high-intensity synchrotron radiation sources with x-ray beams millions of times the intensity of those available from conventional x-ray tubes. Today there are more than 20 such facilities in the world and more are being built. The original facility at Stanford is still operating for ten months per year, 24 hours per day, and has 1500 users, of which 35% are from biomedical sciences, 30% are from condensed-matter physics, 15% from chemistry, 10% from environmental sciences and 10% from other areas. Environmental sciences are currently the fastest growing area, although five years ago they were almost non-existent. The National Institutes of Health which fund biomedical research find the facility so valuable that it will pay half the cost of an estimated $50 million upgrade that is soon to begin.

The leading biomedical application at the synchrotron light source is what is known as structural biology, whereby x-ray diffraction is used to get a picture of the atomic structure of a biologically interesting substance. Recently the cholera toxin has been analyzed. It looks much like the Apollo moon lander of the 1960s. It has four feet that attach it to the cell wall, a rectangular body that houses a drill that penetrates the cell wall, an elevator that transports the toxin into the cell, and the toxin itself which lies atop the body. The drug designers now have four ways to attack cholera: block the ability of the feet to attach, disable the drill or the elevator, or neutralize the toxin.

Here in Britain you have a synchrotron radiation facility at the Daresbury Laboratory. It has never been properly supported with funds for running time or for the necessary modern instrumentation, and so has been much less productive than it might have been. It was one of the earliest of the dedicated synchrotron light sources, and the lost opportunity has been damaging to your science programme. You have another accelerator facility at the Rutherford Laboratory – the ISIS facility that is the second most powerful spallation neutron source in the world. It has a 600-kW beam on its target and the neutrons produced are used for materials science, biology, etc. Its support has been better than Daresbury's, but I do not believe that maximum advantage has been taken of its potential.

The problem here may be that British funding agencies look at their facilities too narrowly. In the United States the Department of Energy funds my laboratory, and the Department of Energy has programmes in high-energy physics, materials science, condensed-matter physics, biological and environmental sciences, etc. It is, therefore, much easier for me to convince the powers-that-be in Washington that accelerator physics is an important enabling technology than it is here, because the agency that I am trying to convince has responsibilities in many areas.

I have used the linkages between high-energy physics, accelerators and biology as an example of something not well appreciated by government funding agencies. In the hierarchy of sciences that enable other sciences, I would put mathematics at the top, physics next, chemistry next and biology at the bottom. The flow of ideas, techniques and technology is downward. It is because of this that the Director of our National Institutes of Health, Dr Harold Varmus, has said that the continued advance of the biomedical sciences requires the advance of all science. Dr Varmus's statement is extremely important in the United States because the biomedical sciences are currently the most favoured of the science areas, and the National Institutes of Health have more money than any other of the federal agencies that fund science. Biomedical science is getting the favoured treatment in Great Britain as well, and I hope that the message is remembered here.

"Interdisciplinary", in its usual sense, is understood as meaning members of different scientific disciplines working in common on problems in some particular area. There has been a great deal of this in the past, and it has given rise to such new disciplines as biophysics, physical chemistry, biochemistry, chemical engineering, etc. These disciplines are now established and have their own funding mechanisms. What is of more interest is the move that is happening now of new people into new areas, particularly into biology. There is much happening. The premier journal of the physicists is *Physical Review Letters* which now has a new section in its Table of Contents called, "Interdisciplinary Physics: Biological Physics, Quantum Information, etc". Here are a couple of articles from recent issues:

- "Effects of Colored Noise on Stochastic Resonance in Sensory Neurons" [PRL **82**, 2402, (1999)] showing that a particular kind of noise, called 1/f noise that is present in systems of neurons, can in fact improve the sensitivity of neurons to small signals;
- "Protein Folding in Contact Map Space" [PRL **82**, 652, (1999)] studying how to predict the three-dimensional conformation of a protein from its amino-acid sequence.

Both of these problems are of great importance, and new people are bringing the tools and perspectives of the different branches of science to biology with considerable impact.

New programmes

Of particular interest is the attempt to create new interdisciplinary programmes at several major US universities. At Stanford University, Professor Steven Chu, the 1997 Nobel Laureate in Physics, is the spearhead of an effort to create a new programme called Bio-X, where X stands for physics, chemistry, mathematics, computational science and engineering. Bio-X hopes to bring together a large group of faculty in the same building to facilitate the exchange of ideas and the development of new kinds of biological programmes. Chu became interested several years ago when he, more or less for the fun of it, used his laser-based atomic manipulation techniques to measure the spring constant of DNA. If you pull on the DNA double helix it will stretch, and the stretching is important in, among other things, determining the stability of DNA in the cell and its resistance to breakup. Stanford University and the involved faculty are trying to raise the funds for the programme, and merely to house it will call for from $50 to $100 million.

What is happening is that some of the best scientists in areas outside of biomedical science are becoming interested in biomedical problems. They bring a new perspective and new kinds of analytic techniques and theory to bear on problems in biology, a discipline only just now becoming a quantitative science. Some people, including my President, Bill Clinton, have said that the 20th century is the century of physics, while the 21st century will be the century of biology. It may be true, but not in the narrow sense that might be implied by such a statement. From my perspective, biology began its advance when it discovered the existence of the atom, and it will continue its advance only by bringing more of mathematics, physics and chemistry to bear on its problems.

Funding

The critical issue in realizing the potential of new disciplinary areas is funding. It is not solved in the United States, it is not solved in Britain, and it is certainly not solved in the European Union whose "Framework" programmes have produced little output at great cost. All scientific funding systems are set up on disciplinary lines. For example, our National Science Foundation has programme offices for particle physics, astronomy, materials science, condensed-matter physics, chemistry, mathematics, biology, computing, etc. Each office operates through a system of peer review and each office has more good proposals than it can fund. Interdisciplinary programmes have a hard time making the funding cut. If you think of the system as a kind of matrix with columns and rows, the NSF has bosses for columns but no bosses for rows, and so there are very few programmes that cut across the disciplinary columns.

At Stanford some years ago I was a member of a programme committee that set up Stanford's History of Science Program – a joint programme of the History Department and Philosophy Department. When our programme committee found a great candidate for the History of Science faculty, the candidate had to be approved by both department faculties. All too often the historians found the candidate too philosophical while the philosophers found the candidate too historical. That is what happens most of the time in interdisciplinary science programmes. One of your research councils, the Particle Physics and Astronomy Research Council, has before it a proposal to join in a new space experiment called GLAST (Gamma-ray Large Aperture Space Telescope). Different aspects of the GLAST proposal are of interest to the astronomers and to the particle physicists, and so PPARC is having a hard time deciding what to do with it.

Science ordinarily operates best through a system of peer review whereby proposals for funding are evaluated by the experts in the field for their scientific potential and for the ability of the proposers to carry out the work. New disciplinary areas of science don't fit this mould well, for there are no peers to do the reviews. There is no neat solution to this problem. In the United States and in most places the standard organization of science funding agencies is a collection of stovepipes – tall, narrow, disciplinary cylinders. It is not easy to break out of the stovepipes. All I can recommend is that funding agencies give more discretion to programme people to allocate resources based on the reputations of the people proposing the work and the work's potential interest as evaluated at some level above the disciplinary programmes. It should be clear to you from this fuzzy comment that I don't really have a precise answer, no-one does. The only way to proceed is by taking some risks.

In venture capital – an area in which I have some experience – for every ten start-ups, six go bankrupt, three limp along and one is a big winner. That is what fuels things like Silicon Valley. Think of investments in new interdisciplinary research as would a venture capitalist. Take the risk and, if one in ten is a winner, honour the risk taker. If you do that and do not take too short a view, perhaps you will even capture a unicorn.

POSTGRADUATE EDUCATION FOR UK PLC

The Foundation held a lecture and dinner discussion on "Postgraduate Education for UK plc" on 4 March 1999 at the Royal Society. The Rt Hon The Lord Jenkin of Roding was in the chair and the evening was sponsored by ESRC, NERC, the UK Council for Graduate Education and The Wellcome Trust. The speakers were Professor Robert Burgess, Pro-Vice-Chancellor, University of Warwick, and Vice-Chancellor Elect, University of Leicester, Dr David Clark, Director, Engineering and Science, EPSRC, and Professor A Ledwith CBE FRS DSc, President, The Royal Society of Chemistry.

Dr David Clark*

Summary: Dr Clark said more needed to be done to provide high-kudos exit for bright young postgraduates from academe to the external workforce. He had a number of concerns about the current state of postgraduate training which he discussed.

The universities are the source of much of the nation's knowledge and, all importantly, much of the nation's expertise. We need to encourage the flow of bright young people, at all levels (graduate, postgraduate and postdoctoral), out of the intellectual "hothouse" of academia and into industry, commerce and the service sector, where they can contribute to the overall well-being of "UK plc".

Governments invest in academic research and postgraduate education for a variety of reasons: to contribute to industrial competitiveness, to improve public health and personal well-being, to develop the national infrastructure, and so forth. Advancement of knowledge for reasons of culture is also a legitimate investment for public moneys. But for knowledge to be used effectively, it needs to "flow" to the point of use; and for postgraduates to make best use of their expertise they must remain alert to the full range of career opportunities.

The path from undergraduate life to an eventual successful career has been likened to a game of snakes and ladders. There are snakes aplenty for the unsuspecting graduate: a poor degree, an inappropriate postgraduate course, a second-rate supervisor, a cycle of short-term research contracts, are just a few examples of "snakes". The universities, and the agencies that fund them, have a responsibility to ensure that undergraduates, postgraduates and postdoctorals are warned of the potential "snakes" and to ensure that there are "ladders" available for the most able.

Universities do an excellent job in providing career advice for graduates. For postgraduates it is not so obvious that appropriate advice is always available. The past twenty years has seen the number of researchers on fixed-term contracts quadruple. Whilst a fixed-term postdoctoral appointment is likely to be a "ladder" to a research career in academe or industry, the third or successive contracts could well be "snakes". More needs to be done to provide high-kudos exit routes for bright young postgraduates from academe to the external workforce. And more needs to be done to provide advice on the wide range of career options.

I have a number of concerns about the current state of postgraduate training (at both the masters and doctoral level). The first is the quality of the postgraduate intake. In the past 30 years the nation has moved from an elite to a mass higher-education system; from 50,000 graduates to 250,000 graduates each year. There are real issues relating to quality in this spectacular expansion. The second concern relates to the quality of supervision. The spectacular expansion in postgraduate student numbers greatly exceeds the modest expansion in the numbers of academic staff. It is just not humanly possible for even the most gifted and hard-working academic to give the same time to the supervision of, say, fifteen doctoral students that their predecessors could have given to, say, five. The third concern relates to the quality of the training environment. Although the Joint Infrastructure Fund will help make good decades of under-investment in academic research laboratories, there is much catching up to be done. The forth concern relates to the quality of flow of postgraduates to industry, commerce, the service sector and government.

It is no longer possible to train someone in their early twenties and hope that their knowledge and skills will be appropriate for several decades of employment. Continual Professional Development is becoming increasingly important, to allow young scientists and engineers to gain an injection of training at the postgraduate level at appropriate times in their early careers. Such training is likely to be modular, may involve new technology (eg the Internet), and could be work-based. Modules might be accumulated to provide an appropriate form of recognition (a Masters

* *Director, Engineering and Science, EPSRC*

degree, or diploma).

In meeting the nation's future needs for a highly skilled workforce in science and engineering at the postgraduate level, there are a number of inter-related challenges to be addressed:

- Attracting young people into science and engineering;
- Improving the public perception of science and engineering;
- Improving the engagement of politicians and senior civil servants in issues relating to science and engineering;
- Understanding the needs of industry and other users of science and engineering;
- Maintaining a healthy academic base.

Alongside all these issues is the most important of all -stimulating a healthy flow of bright young postgraduates into a wide range of careers. The universities need to provide them with the skills and knowledge necessary to enable "UK plc" to prosper.

▲ *From left: Sir Richard Morris, Dr Ken Edwards and Sir Peter Swinnerton-Dyer pictured at the event.*

▲ *Dr Neil Chalmers, Director of the Natural History Museum, talking to Lady Butterworth (right) and Dr Nancy Lane.*

PROFILES OF COUNCIL MEMBERS

ALBERT R C WESTWOOD DSc FREng

His visitors are immediately struck by his youthful energy and enthusiasm – the youthfulness enhanced by his red hair – yet Bert Westwood is a man with a retirement home in New Mexico and a distinguished scientific career in America behind him, who has chosen to postpone his retirement to undertake the challenge in Britain of running the Council for the Central Laboratory of the Research Councils (CLRC) – and is clearly enjoying every moment of his choice!

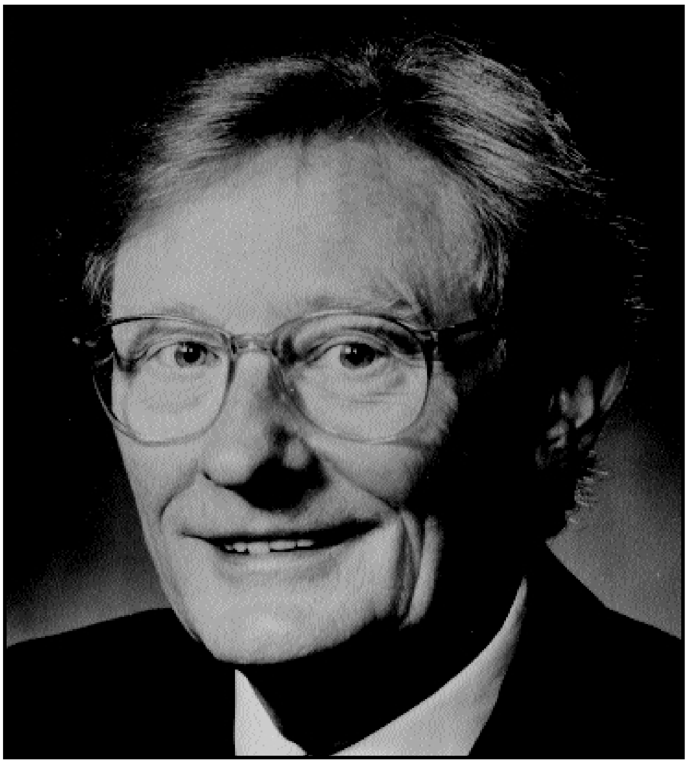
He was educated at King Edward's School, Birmingham, and at Birmingham University where he was awarded his first degree, and his doctorate in metallurgy by the age of 24, and was considerably influenced by his Professor, Alan Cottrell, and his style of thinking and international outlook. He joined ICI Metals Division in 1956, but was frustrated (wrongly, he now thinks) when an early scientific success was not quickly exploited in the marketplace. In 1958, he decided to follow the 'brain drain' to America, and he joined what became the Martin Marietta Laboratories (latterly the Lockheed Martin Corporation) in Baltimore. The company was interested in space research, but was unhappy with the way that space science was being addressed so it decided to create its own 'think tank' and, in so doing, gathered together a talented and international staff, many of whom went on to become noted scientists. Dr Westwood joined that group and began a forty year period of service to the Company – he had intended to stay in the US for two years only but the American qualities of decisiveness and professional trust proved seductive. In 1974 he became Director of the Laboratories, in 1984 Corporate Director of R&D, in 1987 Vice-President of R&D and, in 1990, Corporate Vice President, Research and Technology. He planned to retire firstly in 1992, but instead moved to New Mexico, serving as Vice President, Research and Exploratory Technology at Sandia National Laboratories, until he retired in 1996 ... only to join CLRC in 1998.

He remembers the early 1960s as an exciting time to be in materials science when ideas and their encouragement proliferated. He soon found an interesting research topic in the effects of environments on the deformation behaviour of materials and – almost by return post – was supported by a grant to the extent of his own salary and that of two technicians. He considers himself fortunate to have worked with some of the best minds in his field both in America and elsewhere and, particularly, in Russia where he has made many good friends. A man who talks simply and well about his subject should perhaps have undertaken his research in a university where he could teach as well, but, when so challenged, he admitted to an especial liking for the decisiveness and competitiveness of scientific research in industry.

Dr Westwood was already married with one child when he went to America. His wife is a professional singer and she has performed all over the world with Bert as accompanist – in fact, he might have become a professional pianist had other talents not diverted him. His interest in the arts extends to serving on the Maryland and New Mexico Humanities Councils, of which he has been Treasurer, Secretary and Chairman, Chairing the New Mexico Symphony Board, and fundraising for the Santa Fe Opera. But, like so much of his career, such activities have occurred as a result of chance rather than any predictable career plan.

He is not a religious man ... in the sense that he does not believe in a benign God, for which he sees no evidence. However, he does not necessarily think that there is no creative power. He was brought up in the Presbyterian Church, becoming an Elder, and its teachings established a pattern of behaviour that has encouraged him to concern himself with those needing help, such as scientists in Russia, for whom the lack of funding for up-to-date equipment is proving disastrous. He applauds the Americans who are now putting money into the education of young Russian scientists – the seedbed of the country's future development. The changes in Russia have been of considerable concern to him in respect of their effect on the development of science, where, he believes, the scientific talent is tremendous but where its progress will be impeded for at least another generation.

Why should he postpone his busy retirement in an ideal location after a very successful career with the same company, some one hundred and twenty research publications, a clutch of awards (the Beilby Gold Medal, the Leadership Award of the Metals, Minerals & Materials Society, the Centennial Medal of the University of Maryland, and Acta Metallurgica's J. Herbert Holloman Award), election to a variety of Fellowships and Academies, including the US, UK, Swedish and Russian Academies of Engineering, and a plethora of distinguished lectureships, presidencies and chairmanships? He is on record as saying that, after forty years in America and in return for his first class education at the expense of the British taxpayer, he felt that he had not paid his dues here (does one hear in that the echoes of the Protestant work ethic?). Some will suspect that Dr Westwood is much too active to begin retirement any time in the near future, and that the post of Chairman and Chief Executive of the CLRC was just so challenging that he could only accept it when approached. He has set himself to be an agent for change at the Council and is in the process of introducing the sort of pro-active "best practices" that are common in the USA. He notes that whereas American National Labs are beginning to serve a variety of customers, the UK's Central Research



▲ *Dr A R C Westwood, copyright Rutherford Appleton Laboratory*

Laboratory (CLRC) is largely focused on the provision of facility support to universities, and is only just beginning to recognise the possibility of providing similar "Science base" support to industry and the defence sector, and the need to apply some of their creative talents to wealth generation. He believes that the CLRC's scientists are absolutely first class, and do not need any help from him, but that the quality of their work is not as widely recognised as it should be. So increasing the visibility of the Lab's work is important, as are creating a more secure financial basis and efficient administrative structure, and an integrated and forward looking management team.

He certainly gives the impression of being a fulfilled man and he opines that this is because of his three separate lives: a science life that is intellectually stimulating, a management life that provides opportunities for both leadership and mentoring, and a complementary life in music and the humanities that provides perspective. The challenge of his retirement – if and when it comes – will be to compose beautiful songs ... rather than merely "arrange" them.

FOUNDATION NEWS

Lord Lloyd of Kilgerran Prize 1999

The Foundation's Council has awarded the 1999 Lord Lloyd of Kilgerran Prize to Professor Jane Plant CBE, the Assistant Director of the British Geological Survey. The award is in recognition of her contribution to the application of fundamental geochemical modelling and sound observation in the development of simple, cost-effective methods of minimising the impact of contamination on the environment, and particularly human health. The application has already reaped benefits both in the UK and in the developing world.

The prize was established to mark the many rich aspects of the life of the late Lord Lloyd of Kilgerran, second Chairman and first President of the Foundation for Science and Technology.

Discussion summary sheets

The Foundation produces a single sheet summary of the discussion at its lecture and dinner discussion. They show the names of the speakers, the sponsors for the evening and a summary of the discussion. No names other than the speakers are mentioned since the record must be in line with the "Chatham House Rule".

Where Members cannot attend a meeting but would like a copy of the summary, they should send a stamped addressed envelope with a note saying which summary they require.

Shared Sponsorship Scheme

The Foundation is extremely fortunate in having the support of those who contribute to the Shared Sponsorship Scheme, this being an important aspect in the preparation of the Foundation's programme. Those contributing for 1999 are:

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New Associate Members

The following have become Associate Members of the Foundation for Science and Technology:

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Union Railways (North) Ltd
Contact: Mr Walt Bell, Managing Director

Learned and Professional Society News

Sales of the 1999 Salary Survey in respect of the staffs of learned and professional societies (at a cost of £10 per copy) and of the Register of Learned and Professional Societies 1999 (at a cost of £15) are going well. The June issue of the Newsletter contained, free of charge, a publication listing a variety of conference and meeting venues and facilities available to societies which was published for several years by Chameleon Press Ltd but which has now been taken over by the Foundation and will be published once each year: it has proved popular and a number of alterations and additions have been submitted.

The June Newsletter also contained an article on VAT and the 'business/non business' categorisation by Kevin Woolridge of Huntley Fowler, Chartered Accountants, in addition to the usual digest of information for societies culled from a myriad of sources.

The proposed July seminar on 'The Efficient Use of Resources' had to be postponed because there were only five registrations but it will be offered again in due course because of its importance as a topic. Arrangements have been settled, at the time of writing, for the joint seminar with the Association of Learned and Professional Society Publishers on the Future of Learned and Professional Societies: Threats and Opportunities in the Twenty First Century, and for the reintroduced Annual Luncheon with Lord Neill of Bladen QC, who is the Chairman of the Committee on Standards in Public Life, as guest of honour. The seminar programme for the following few months will comprise: Inspections: What are they about? (December); Alternative Working Practices (February); and Towards an IT Strategy (April).

The two recent Foundation Working Parties have both completed their discussions: one directed itself to subscriptions and the benefit rule in respect of deeds of covenants, while the other considered issues in relation to the HMG review of charity taxation. The first produced a useful case study published as an occasional paper and the other submitted its comments to HMG which have also been published in the Newsletter.

▲ *Event with Royal Dublin Society.*
When the Foundation held an event jointly with the Royal Dublin Society (TI&S, Spring 1999, page 8) two of those shown here were greatly responsible for inviting the Foundation and for the success of the venture. Carol Power (left) is on the Society's staff and Chris Shouldice is Chairman of the Society's Science and Technology Committee.

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Laing Technology Group
Leeds University
Leicester University
Liverpool University
Lloyd's Register of Shipping
London Guildhall University
Loughborough University
LSI Logic Europe Ltd
Lucas Varity plc
Luton University
Mainprice Napier & Co.
Management Technology Associates
Manchester Metropolitan University
Manchester University
Merck Sharp & Dohme
Meteorological Office
Metropolitan Police Service
Microsoft Research Ltd
Middlesex University
Ministry of Agriculture, Fisheries & Food
Ministry of Defence
Napier University
National Grid Company plc
Natural History Museum
New Property Cases Ltd
New Product Research & Development
Newcastle University
Nortel Ltd
Nottingham Trent University
Novartis UK Ltd
Nuclear Electric plc
Office of Science & Technology
ORBIC (International) Ltd
Ordnance Survey
Ove Arup Partnership
Oxford Innovation Ltd
Oxford Natural Products plc
Oxford University
Parliamentary Office of Science & Technology
Perrotts Group plc
Pfizer Central Research
PowerGen plc
Premmit Associates Ltd
Public Record Office
Queen Mary and Westfield College
Railtrack plc
R&D Efficiency
Reading University
Research into Ageing
RHM Technology Ltd
RINGI Ltd
Roche Products Ltd
Royal Botanic Gardens, Kew
Royal Commission for the Exhibition of 1851
Royal Commission on Environmental Pollution
Royal Holloway & Bedford New College
SAP (UK)
Science Policy Research Unit
Science Policy Support Group
Science Systems
Scottish Higher Education Funding Council
Severn Trent plc
Sharp Laboratories of Europe Ltd
Sheffield University
Shell UK Limited
SmithKline Beecham Pharmaceuticals
Software Production Enterprises
Southampton University
South Bank University
Sunderland University
Surrey University
Sussex University
Technology Colleges Trust
Teesside University
Thames Water Utilities Ltd
The British Academy
The D Group
The Engineering Council
The Open University
The Royal Academy of Engineering
The Royal Society
The Smallpeice Trust
Thorn EMI/CRL
Trade Association Management Ltd
UK Council for Graduate Education
Ulster University
UKERNA
UK Nirex Limited
UMIST
Unilever plc
Union Railways (North) Ltd
University College London
University of Kent at Canterbury
University of the Highlands & Islands
Warwick University
Wates Technology
Westminster University
Westport Energy Corporation
Winsafe Ltd
WIRE Ltd
Wolverhampton University
WRc plc
WS Atkins Consultants Ltd

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