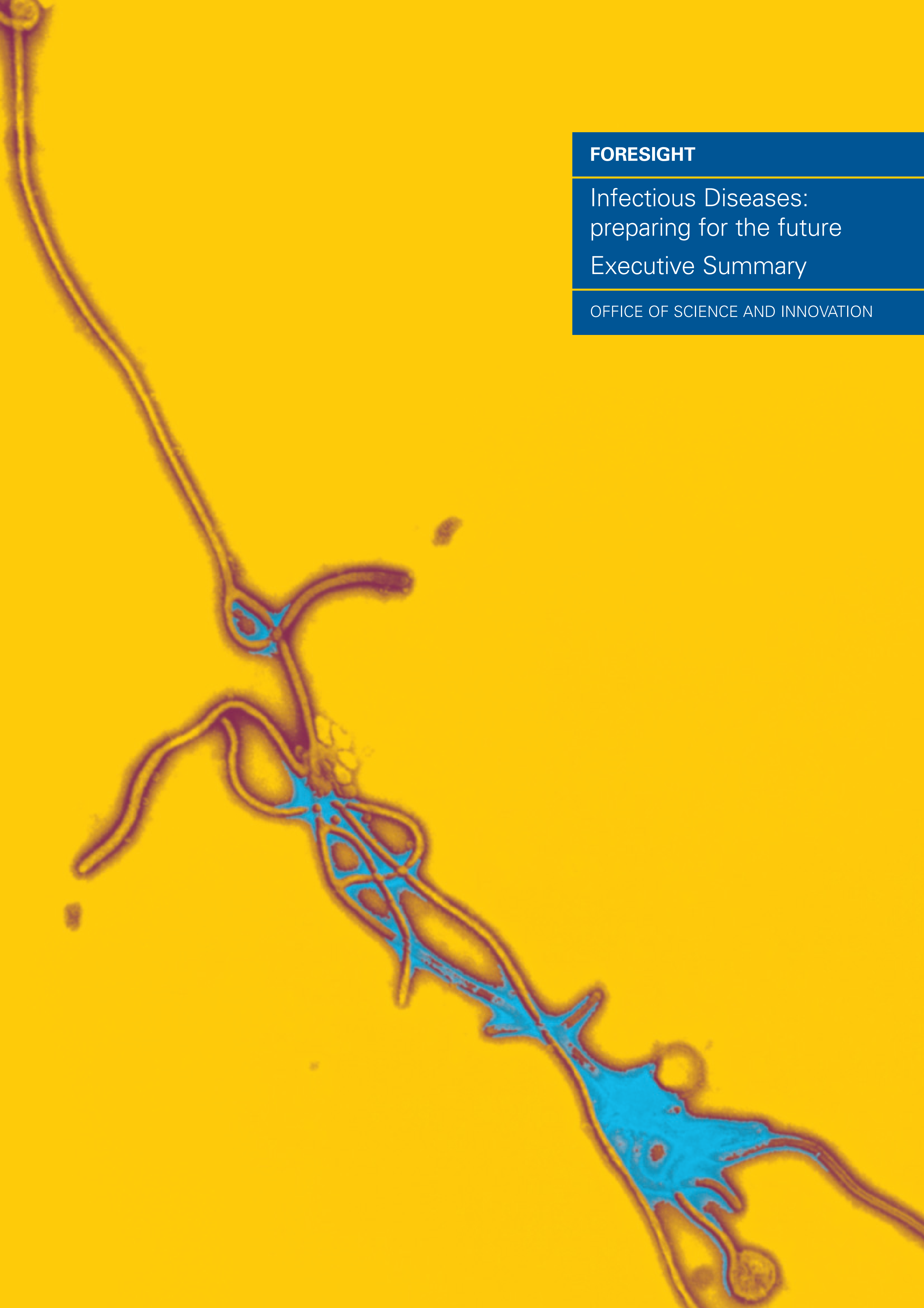

FORESIGHT

Infectious Diseases: preparing for the future

Executive Summary

OFFICE OF SCIENCE AND INNOVATION

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Infectious Diseases: preparing for the future

Executive Summary

This report is intended for:

Policy makers concerned with infectious diseases in humans, animals and plants. It will also be of interest to a wide range of disease management professionals, people in industry and business, and researchers in natural and social sciences. The report takes an international perspective and will therefore be of interest to governments and non-governmental organisations across the world.

This report has been produced by the UK Government's Foresight project: Infectious Diseases: preparing for the future. Foresight is run by the Office of Science and Innovation under the direction of the Chief Scientific Adviser to HM Government. Foresight creates challenging visions of the future to ensure effective strategies now.

Foreword

Infectious disease affects us all. Human diseases have a profound effect in countries across the world, causing premature deaths and disability. In some countries, HIV/AIDS has contributed to a reduction in life expectancy to around 40 years. Diseases in plants and animals act as barriers to economic development and also threaten ecosystems.

I commissioned this independent scientific study to asses how the future threats of disease might evolve over the next 10-25 years, and to assess how science could help in managing them – specifically through new systems for disease detection, identification and monitoring. The work has looked at both developed and developing countries, with a particular focus on sub-Saharan Africa.

I would like to mention two important findings. Firstly, infectious diseases are diverse and dynamic; new outbreaks occur frequently and we are discovering new infectious agents year on year. This argues the need for policies that are flexible in relation to an evolving threat, and which can address a wide spectrum of possible diseases.

Secondly, new detection, identification and monitoring systems could provide a step-change in our capability to manage diseases in the future. However, this potential will only be realised if the deployment of the new systems takes careful account of local systems of culture and governance, and provided the systems are integrated with effective control measures.

I would like to personally thank the many national and international organisations that have been involved in this work, as well as the 300 or more experts from nearly 30 countries. The breadth and depth of perspectives that they have contributed is, I believe, unprecedented. The findings therefore provide a considerable body of scientific analysis and fresh insights to inform policy development by stakeholders at both national and international levels. I therefore have pleasure in making the full results and work of the project available for the benefit of all.

Sir David King KB ScD FRS
Chief Scientific Adviser to HM Government, and
Head of the Office of Science and Innovation

Preface

I am delighted to receive this international Foresight report from Sir David King. It embodies the use of excellent science to inform long-term policies for the management of infectious disease.

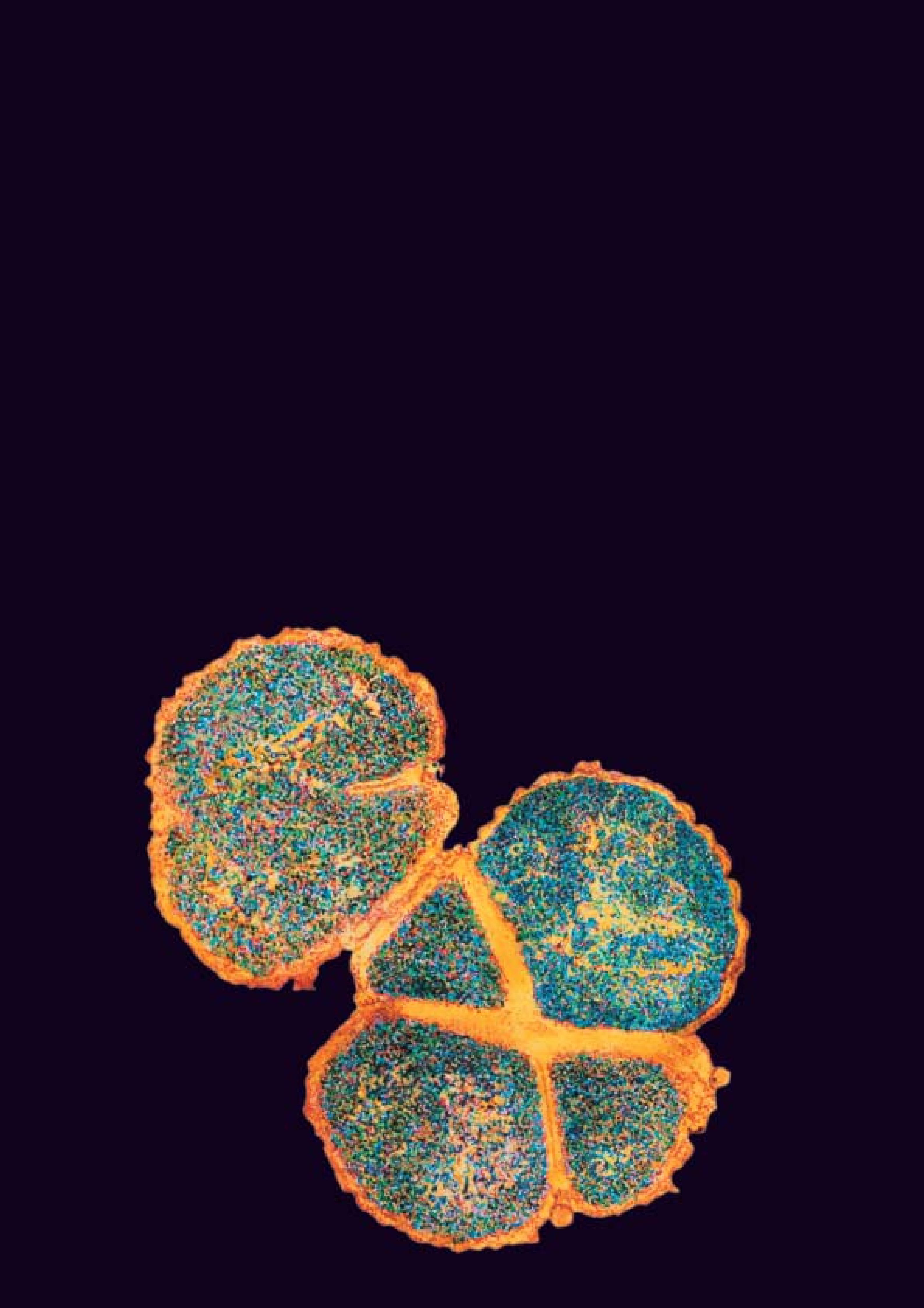
We cannot eliminate the risks of infectious diseases, but we can seek to manage them more effectively. Here, new systems for detection, identification and monitoring can play a vital role. Indeed, this project has shown that future systems could transform our capabilities for fighting the evolving threat – both in developing and developed countries.

I particularly welcome the broad perspective of this work – which considers future diseases in humans, animals and plants. Human and animal diseases are closely linked since many pathogens have the potential to jump from one species to another. Also, the control of diseases in livestock and plants are closely linked to human health, through their effect on economic development and trade.

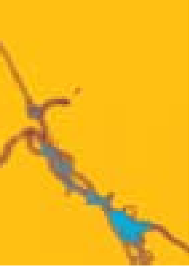
Sir David's report has highlighted the key role that science can play in the future in managing the evolving risks. However, science is not enough in itself. There are many issues and choices that policy makers and professionals involved with disease management need to address, to realise the maximum benefit from these developments. Importantly, this report sets out what those key issues and choices are.

I am keen to capitalise on the valuable scientific resource the project provides. I have therefore worked with key players in national and international organisations to take the findings forward. This project publishes the first steps, setting out how the findings will be used to inform policy development and investment strategies. I am particularly pleased that many actions are already well in hand.

Willy Bach
Parliamentary Under-Secretary (Lords):
Sustainable Farming and Food
Department for Environment, Food and Rural Affairs



Contents



1 Introduction

The aim of the project

To use the best available science to evaluate the threats of infectious diseases[1] in humans, animals and plants over the next 10-25 years; and to produce a vision for their management, specifically through systems for detection, identification and monitoring.

An international approach:

While the UK Office of Science and Innovation commissioned the work, it has involved over 300 leading experts and stakeholders from nearly 30 countries, as well as many international organisations.

An independent scientific look:

The findings are the result of independent scientific analysis – they do not constitute the policies of governments or any organisations involved in the work.

A uniquely broad perspective:

This sets the Foresight project apart from other studies:

- It has looked across diseases in humans, animals and plants.
- It has involved experts from diverse disciplines – from social sciences to genomics, and from Earth observation to epidemiology.
- It has compared the situation in developing and developed countries – sub-Saharan Africa and the UK have been used as examples.

[1] In this report, 'infectious diseases' is taken to include those diseases resulting from infections by transmissible agents such as viruses, bacteria, fungi and parasites.

Why the study was needed

Despite some notable successes, the fight against infectious diseases is far from won. New systems for detection, identification and monitoring (DIM) could transform our capabilities in managing the threat – but this will crucially depend on decisions taken today. What are the choices and what are their implications?

In recent decades, societies have struggled to manage existing diseases, while, at the same time, a succession of new and novel pathogens has emerged, such as HIV, BSE, and cassava mosaic disease. The emergence of drug-resistant strains has added to the threat.

Science is a powerful tool in the battle. In this project, we have used it to analyse how the risks could change over the next 10–25 years, and why. And it has provided a vision of new technology for the fight – DIM systems that could offer a step-change in capability.

However, realising the benefits of these new systems will depend on many difficult choices – for governments, stakeholder organisations, and for the public. Issues of regulation, governance, ethics, and civil liberties will all be important.

Defining ‘detection’, ‘identification’ and ‘monitoring’ (DIM)

Outbreaks of infectious disease can spread rapidly, causing enormous losses to health and livelihood. The best strategy is to stop their spread at an early stage, or prevent them altogether.

To do this, we rely on very early **detection** of the appearance of disease or disease-causing agents. Rapid and accurate **identification** of these agents is essential if we are to stop outbreaks with the correct control measure, for instance, antimicrobials or vaccines. This is particularly true for entirely new diseases, where we find ourselves in a race to develop new controls as the disease spreads. In outbreak situations and control programmes, **monitoring** of a known problem will involve the same systems of detection and identification and is important, as it informs where to focus effort.

2 The threat of infectious diseases – today and in the future

Q1 What is the threat of infectious diseases today?

Q2 What is the vision of our world leaders for infectious diseases in the future?

Q3 How might the threat evolve over the next 25 years?

Q4 What major epidemics might emerge in the future and how bad might they be?

Q5 What factors will drive changes in risk?

Q6 How might climate change impact on infectious diseases?

2 The threat of infectious diseases – today and in the future

This chapter examines how the threat of infectious diseases could evolve over the next 10–25 years, using the present day as a baseline. It looks at both the UK and sub-Saharan Africa, and also considers factors driving changes in risk.

Important categories of future diseases are identified, paying particular attention to new and emerging diseases. These are of special concern, since they imply the need for disease management policies that are both flexible and adaptable.

The effect of climate change is also considered, taking a 75-year horizon.

2 The threat of infectious diseases – today and in the future

Q1 What is the threat of infectious diseases today?

Infectious diseases in humans now threaten us all – and with our assistance, can cross the globe in hours. Worldwide, they account for over a fifth of human deaths and a quarter of morbidity. They disproportionately affect the poor – in some African countries, they have contributed to reducing life expectancy to around 40 years.

When diseases attack crops and livestock, they can undermine economic development and cause humanitarian crises. Plant diseases account for 10–15% of losses to crop production worldwide, and hit developing countries particularly hard. Livestock diseases also impact on rich countries – the 2001 outbreak of foot-and-mouth disease (FMD) in the UK cost around £7 billion – more than the National Health Service spends on all human infectious diseases in a year.

Fig 2.1: Children in particular, suffer the consequences of infectious diseases

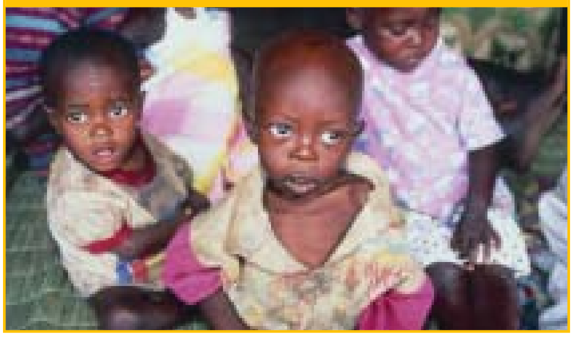


Table 2.1 gives an indication of the scale of the impact of infectious diseases in humans, animals and crops. However, these figures cannot convey the devastating human consequences resulting from famine and displaced populations. HIV alone has created over 3 million orphans in sub-Saharan Africa.

In addition to known diseases, unknown diseases are also emerging, some of which are associated with new and serious disease problems, such as SARS in human populations or BSE in cattle. The emergence of drug-resistant strains is also a problem – 20 years ago we thought that we were winning the fight against tuberculosis, but drug-resistant strains have now emerged.

Animal diseases can cause substantial economic costs to developed countries (Table 2.1), but their effects are most severe in sub-Saharan Africa, which shares the greatest burden of animal diseases worldwide. Here, livestock farming contributes 25% to the gross national product across the region, but 12 of the world's 15 major epidemic diseases of animals are endemic (in the former List A of the World Organization for Animal Health – the OIE (Office Internationale des Épizooties)). In contrast, all are exotic to the UK.

Four staples – rice, maize, wheat and potatoes – make up half of the global supply of food crops. Epidemic diseases that affect these can pose global threats, threatening national food supplies and economic security. The recent re-emergence and spread of wheat stem rust in east Africa, which had devastating impacts in the 20th century, exemplifies such a threat.

Table 2.1: Examples of the impacts of diseases on humans, animals and plants

Mortality for major human diseases – worldwide deaths in 2004 *(derived from the Statistical Annex of the 2004 World Health Report (WHO))*					
Lower respiratory tract infections	**HIV/AIDS**	**Diarrhoeal disease**	**Tuberculosis**	**Malaria**	**Childhood infections[2]**
6.8% 4.0 million	4.9% 2.8 million	3.2% 1.8 million	2.7% 1.6 million	2.2% 1.3 million	2.0% 1.1 million

Examples of animal disease outbreaks, with costs					
BSE, United Kingdom **1996/1997**	**FMD, Chinese Province of Taiwan** **1997**	**Classical swine fever, Netherlands** **1997/98**	**FMD, UK** **2001**	**Avian influenza, Vietnam** **2003/2004**	**Avian influenza, Netherlands** **2003**
£2.3 billion	£4 billion	£1.4 billion	£7 billion	£0.32 billion	£0.4 billion

Examples of plant disease outbreak, with costs			
Southern corn leaf blight, USA **1970**	**Soybean rust, Brazil** **2001–2004**	**Groundnut rosette virus, sub-Saharan Africa** **1900 to present**	**Cassava mosaic disease, Uganda** **1990–2000**
£0.6 billion losses in a single year	£3 billion in accumulated losses since introduction in 2001	15 episodes, with losses of up to £200 million per epidemic	£40 million lost annually from this new virus variant

Q2 What is the vision of our world leaders for infectious diseases in the future?

The eight Millennium Development Goals (MDGs) provide a vision of the world our leaders would like to see in 2015. Infectious diseases crucially affect four, which relate to human health, food supply and economic development. For these, progress has been poor: in Africa the situation has remained unchanged or has even deteriorated. Across the world, many of the individual targets are not on-course to be met.

Table 2.2 details current progress against targets set for four MDGs that are particularly relevant to infectious diseases – three geographical regions have been selected for comparison. The colour coding provides an indication of progress, and the likelihood of achieving the targets by 2015, if current trends persist.

[2] Pertussis, poliomyelitis, diphtheria, measles, tetanus.

It is striking how many of the MDGs relate to infectious diseases, and how many are not currently on course to succeed. This argues strongly for reassessing the role and priority given to the management of infectious diseases in meeting the MDGs.

Table 2.2: Progress in Millennium Development Goals that relate to infectious diseases

Source: UN (September 2005) Millennium Development Goals: Progress Chart. DPI/2363 Rev.2. September 2005.

Millennium Development Goal	Specific target	Sub-Saharan Africa	Southern Asia	Europe
Goal 1: Eradicate extreme poverty and hunger	Reduce extreme poverty by half	Pink	Green	Yellow
	Reduce extreme hunger by half	Yellow	Yellow	Green
Goal 4: Reduce child mortality	Reduce mortality of under 5s by two-thirds	Pink	Yellow	Yellow
Goal 5: Improve maternal health[3]	Reduce maternal mortality by three-quarters	Pink	Pink	Green
Goal 6: Combat HIV, malaria and other diseases	Halt and reverse spread of HIV/AIDS	Pink	Pink	Pink
	Halt and reverse spread of malaria	Pink	Yellow	Green
	Halt and reverse spread of tuberculosis	Pink	Yellow	Pink

Pink	Yellow	Green
No progress, or a deterioration or reversal	Target not expected to be met by 2015 if existing trends persist	Target expected to be met by 2015 if prevailing trends persists; or not considered important in the region

Q3 How might the threat evolve over the next 10-25 years?

While there is great uncertainty about the future, we should expect many of today's major human and animal infectious diseases to broadly continue in importance – indeed, it could be decades before some, like HIV, will peak. However, we should also expect diverse diseases to continue to emerge or re-emerge. Infectious diseases will continue to jump between wild and domesticated animal species and humans.

The emergence of drug-resistant strains in diseases of humans and animals, and biocide-resistant strains in plant diseases, will be particularly important – as will the spread of diseases to new areas due to increased travel, migration and trade.

[3] The available data for maternal mortality does not allow trend analysis. Progress represented in this chart has been assessed by responsible agencies using proxy indicators.

The great majority of emerging and re-emerging human infectious diseases have originated from animal sources. It is therefore expected that the animal reservoir, particularly in wild animals, will be an important and continuing source of infectious diseases in both livestock and humans, due to incursions into natural habitats and the trade in meat and exotic animals for food and pets.

Fig 2.2: A wide selection of bushmeat for sale

HIV, tuberculosis and malaria will continue to impose a huge public health burden, particularly in developing countries, and may become more difficult to control. For example, 20 years ago it was thought that the battle against tuberculosis was being won. But it is re-emerging, driven by the HIV epidemic and the emergence of drug resistance. Epidemic diseases, such as influenza, will continue to be a threat, and new diseases will continue to emerge. We are currently identifying one or two new human pathogens every year. Most new pathogens will have their origins in animal reservoirs.

For livestock in the UK, it is expected that certain important diseases will remain endemic, for example, bovine tuberculosis. Also, there are new diseases yet to be controlled e.g. porcine respiratory and reproductive syndrome. There is also a concern that the great livestock plagues, such as those in Africa, may be introduced into other countries in the future. In Africa, animal diseases of continuing importance are likely to include contagious bovine pleuropneumonia, peste des petits ruminants and FMD – the latter being the most transmissible and greatest impediment to international market access by sub-Saharan-African countries.

Fig 2.3: Cassava severely damaged by the virulent form of mosaic disease in Uganda at the height of the epidemic in the mid-1990s

For plants, there is evidence that new diseases are entering countries at a growing rate. In the past century in Europe, the number of new plant diseases established each decade has increased. However, this growth has not been apparent in Africa, perhaps because this continent is still to experience a trade-driven burst of new diseases, or more worryingly, because national capacity to detect and diagnose new diseases declined during the last century. Besides the introduction of new diseases, new and virulent plant diseases are arising from local mixing and evolution of strains, such as cassava mosaic disease in east Africa.

Eight important future disease categories

The project experts identified eight classes of disease that were considered particularly important in the next 10–25 years, and where future DIM systems have the potential to make a difference. This list is not intended to be exhaustive, but is considered to be both thorough and diverse in the future challenges it presents for disease management:

1 New pathogen species and novel variants

2 Pathogens acquiring resistance

3 Diseases that cross between animal species to humans (zoonoses)

4 HIV/AIDS, tuberculosis and malaria

5 Epidemic plant diseases

6 Acute respiratory infections

7 Sexually transmitted infections

8 Animal diseases that cross national boundaries (‘transboundary’)

Q4 What major epidemics might emerge in the future and how bad might they be?

No one knows what major diseases may arise in the future – HIV and BSE were novel and took us by surprise. We need policies that are flexible and that can cope with the unexpected. New science may be able to give us some clues of what might be around the corner, but detecting an unusual event in a disease monitoring system might be our first sight of a major epidemic.

Diseases that produce major epidemics are often fast-spreading. However, novel and slow-moving diseases that show no symptoms for many years can be just as catastrophic – HIV is a good example. We do not know how many such diseases are already at large and hidden in the human and animal populations.

Major new diseases will affect developing and developed countries in very different ways. In the former, the new diseases could spread unchecked due to a lack of the basic resources to manage even existing diseases. Similarly, when they affect crops and livestock, the inability to eradicate the disease from the country could severely prejudice economic development and trade.

In developed countries around the world, there is a danger that a major epidemic could reach a tipping point in compromising essential services and business. We will see later in this report how future DIM systems could play an important role within wider disease management strategies, in helping to prevent such tipping points being reached.

Q5 What factors will drive changes in risk?

For human, animal and plant diseases, it is not just the virulence of the disease and its ease of transmission that are important. How the disease interacts with patterns of behaviours and movements of people, and with how we manage our livestock and crops are also crucial. So, some of the new threats of the future could be driven as much from changes in human behaviour and animal husbandry and agriculture, as from new pathogens emerging from the wild.

Several socio-economic effects were found to be consistently important for the UK and Africa, and across humans, animals and plants:

- **Increasing travel, migration and trade:** these promote both the spread of existing diseases to new populations and regions and also facilitate the emergence of new diseases by bringing different populations into contact with each other.
- **Exotics:** increasing levels of tourism in remote areas, growing importation of alien plants for gardens and exotic animals as pets, and consumption of novel foods such as bushmeat are all facilitating the introduction of new diseases from wild species.

Fig 2.4: Increasing travel will promote the spread of diseases to new populations

- **Drug use leading to drug-resistant organisms:** this results, for example, from the use of adulterated drugs, failure to complete courses of treatment, and inaccurate diagnosis.

In Africa, many more factors were considered to have a larger effect on disease risks than in the UK. Such factors include: poverty; conflicts; systems of governance; changing patterns of land use (particularly urbanisation); shifting agricultural practices towards intensification; and the lack of capacity.

For the UK, other important factors affecting future disease risks include: the implementation of international systems of disease surveillance and control; lack of new pesticides for crops, and of drugs and vaccines for animals; and the amount of illegal imports.

China was the subject of a case study to investigate how future changes in society might affect human diseases. The insight provided by this work also has relevance to other parts of the world – see box on China for the key results.

All of the factors mentioned above are uncertain and interact in complex ways. This makes their combined effect on infectious diseases increasingly uncertain the further one looks into the future – how could anyone have predicted that worldwide drug trafficking, sex tourism and the bushmeat trade in Africa would all have played a role in today's epidemic of HIV/AIDS? However, some of the factors are the responsibility of governments acting alone or through international bodies. So, governments could, in principle, develop long-term approaches to managing these factors, with a view to reducing uncertainty and also disease risks.

Q6 How might climate change impact on infectious diseases?

Over the next 75 years, climate change is likely to have most impact on diseases that are vector-borne – i.e. carried by insects. In the UK, there is no imminent threat to the population, although climate change will make the climate marginally more favourable for diseases such as malaria. However, for livestock and crops, the picture will be mixed, with some diseases increasing and some decreasing in risk. In Africa, the effects will be greater because: insect-borne diseases are already much more important there; climate change is expected to alter the geographical ranges of some of these diseases; and there are likely to be limitations in health infrastructure.

The UK is already at the edge of a zone of increased risk of bluetongue virus. This affects sheep and cattle and has spread through southern Europe because of recent climate warming in the region. Plants will also be at greater risk of vector-borne disease as mild winters and warm springs favour the survival and early development of the aphid vectors of numerous pathogens. In some instances, however, very hot and dry summers may reduce threats, for example, where the relevant vectors are water-sensitive – e.g. the liver fluke (fascioliasis).

Fig 2.5: An opportunity for insect disease vectors to stow away

One of the ways insects (and the diseases they carry) gain entry to the UK is by stowing away on boats and, to a lesser extent, on aircraft. The frequency of successful introductions of this type may increase in the short term with climate change.

Africa, where people, animals and crops live in conditions of much greater moisture stress, rising temperature will be important, but less so than changes to rainfall patterns and the frequency of droughts.

Many vector-borne diseases such as malaria and sleeping sickness are major causes of human suffering in Africa. And tsetse- and tick-borne diseases such as trypanosomiasis are major constraints on livestock production and contributors to poverty. Climate change is expected to alter the distributions of some or all of these diseases. For example, the tsetse fly vectors of trypanosomiasis are predicted to alter their distributions by 2030 in response to climate change, some losing their footholds at the southern and northern extremes of their ranges, but some expanding into parts of east and west Africa.

Climate change will also have many indirect effects on infectious diseases, particularly in Africa. For example, it could force patterns of agriculture to change, causing localised famine, displacing populations, and fuelling conflict over scarce resources such as water. All of these will affect the emergence and spread of disease, particularly in animals and humans.

The threat of infectious diseases to ecosystems

Infectious diseases are natural components of ecosystems, contributing to biodiversity and to their dynamic stability over time. However, when natural ecosystems are stressed, disease outbreaks may become more frequent and may have longer-term negative impacts, both on the ecosystems and potentially on society, as most natural ecosystems provide services, such as clean water and air, recreation, tourism, and the 'existence value' of biodiversity.

The greatest hazard to ecosystems arises when diseases affect keystone species that are important to ecosystem function, such as top predators, whose removal may lead to population explosion of herbivores and the overexploitation of plants. In an already stressed ecosystem, these effects may be aggravated, and a capacity to return to pre-disease structure and function reduced. Examples of stressed ecosystems today include over-fished marine systems; overgrazed grasslands and overexploited forests.

During the next 20 years, environmental degradation is likely to continue due to pollution, overproduction, habitat fragmentation and alien species invasions, while the economic value placed on natural ecosystems, particularly in developed countries, will increase.

Perhaps the greatest potential ecosystem-level impact of a new disease would be to undermine global water and geochemical cycles by disrupting the key plant and microbial systems that support them. The probability of this is regarded as very low at present. It is much more likely that new diseases in natural ecosystems will reduce the local abundance and diversity of species and the ecosystem services they provide. Natural ecosystems will, on the other hand, continue to be a major source of wildlife diseases that may threaten agricultural systems and human health.

Fig 2.6: Rainforest deforestation

Infectious diseases in China – a changing country

Important factors affecting the future risk of disease

Around 40 Chinese experts identified the most important factors that would affect the future risk of infectious diseases in animals and humans in the country:

- increasing movements of people, animals and animal products around the country and internationally
- more and greater internal migrations of people
- increasing tourism – from and to China
- increasing amounts of animal waste – causing problems for disposal
- changing sexual lifestyles – these are expected to change in ways that increase the risk of acquiring and transmitting diseases
- changing public attitudes – acceptance of risks from infectious diseases will decline significantly, and there would be greater public demands for safety and protection
- an increase in genetic uniformity in crops and animals
- overall rises in wealth and levels of education.

Many of these factors are similar to those identified for the UK and Africa.

Changing disease risks

Fig 2.7: China – a changing country

The Chinese experts then looked at the trends in the above drivers, and evaluated what these would mean for the future threat of infectious diseases. They concluded that, if the expected trends materialise, and in the absence of countermeasures, the rates of the following are likely to rise:

- infections acquired during hospitalisation or from healthcare clinics
- antimicrobial-resistant organisms
- sexually transmitted infections including HIV
- blood-borne viruses associated with high technology care (hepatitis B and C)
- some food-borne infections
- zoonoses in general
- imported and exotic infections.

3 Options for responding to future challenges – DIM systems

Q7 Why are DIM systems likely to be important in managing diseases in the future?

Q8 What are the potential benefits of the future DIM systems?

Q9 What are the most important factors influencing the effective realisation of the future DIM systems?

3 Options for responding to future challenges – DIM systems

This chapter considers the key roles that future DIM systems could play in managing the evolving threats identified in Chapter 2. In particular, it discusses their contribution in wider disease management systems and provides a broad indication of the benefits they might provide. The issues affecting the effective implementation of the future DIM systems are also discussed.

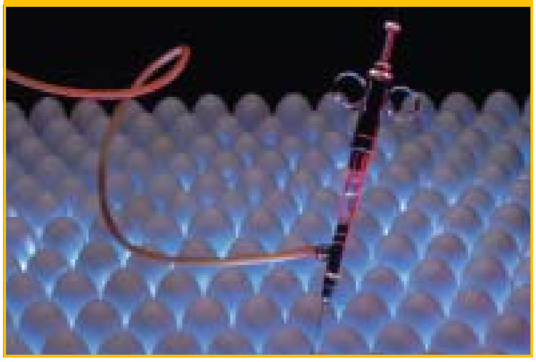
3 Options for responding to future challenges – DIM systems

Q7 Why are DIM systems likely to be important in managing diseases in the future?

Future DIM systems could offer powerful tools for disease management within wider strategies of control. For example, advanced data collection and processing could enable emerging diseases to be quickly spotted, providing valuable time to develop vaccines or to stop their spread in other ways. New techniques for identifying and analysing new pathogens could help us quickly understand how the newly detected diseases will affect populations, and how they could be controlled before widespread damage is caused. And faster, smaller and cheaper diagnostic devices will open up entirely new possibilities for use by professionals and the individual.

Future DIM systems only provide information, and therefore will only yield benefit when linked to timely and effective disease management measures and when properly embedded in disease management infrastructure. However, the information they provide makes three things possible:

Fig 3.1: Vaccine production



- **buying time:** in a potential pandemic of an acute respiratory infection, there is a race between the production and delivery of vaccine and the spread of the virus. Early containment of an epidemic could potentially make more time available for the development and production of a vaccine.
- **enabling more effective and more efficient targeting of resources:** spotting a new emerging disease in its very early stages, for example, by advanced data analysis, could enable resources to be tightly focused and an outbreak to be stopped in its tracks. Alternatively, routine on-the-spot diagnosis of a drug-resistant strain of a disease in a GP's surgery could enable the most appropriate treatment to be provided immediately – this would reduce the need for repeat consultations and save the costs of inappropriate drugs.
- **opening up new possibilities for disease management:** a cheap self-diagnostic device to test sexually transmitted diseases, available from pharmacies in the future, could enable many people who would not normally visit a genito-urinary clinic to test themselves at home. This could bring testing and diagnosis to a large section of the population who have asymptomatic

diseases, which, left undiagnosed, could lead to severe health complications and costly treatment. However, such new possibilities are unlikely to be straightforward – many issues will need to be considered and balanced.

User Challenges: broad classes of DIM system

The project considered four important classes of DIM system for detailed analysis – these are termed 'User Challenges' (UCs):

- UC1: novel information technology for the capture, analysis and modelling of data for the early detection of infectious disease events
- UC2: early detection and characterisation of new or newly resistant/virulent pathogens using genomics and post-genomics
- UC3: taking technology for the identification and characterisation of infectious diseases to individuals by designing smart swabs, or portable hand-held devices (e.g. that analyse fluids)
- UC4: high-throughput screening for infectious diseases of people, animals and plants using surrogate, non-invasive markers (e.g. electromagnetic radiation, volatile organic compounds), for example, in airports, sea/road containers and livestock markets.

Further details of the User Challenges may be found in report D1.

Q8 What are the potential benefits of the future DIM systems?

It is impossible to quantify the benefit of future DIM systems with accuracy. This is because their use and effectiveness will depend on many uncertain factors such as future public attitudes and future systems of governance. However, the project has constructed pen-pictures of the use of new DIM systems 10-25 years in the future. These have been used to illustrate issues surrounding their use, and to consider the benefits they might yield. Whilst these examples are only intended to be illustrative, they have shown that when linked to effective control measures, the new DIM systems could potentially enable substantial reductions in deaths and morbidity, or considerable cost savings.

The following list indicates the benefits that could potentially result from the use of particular future DIM systems, used in association with effective control measures (further details of the examples may be found in project report D1: *A Vision of Future Detection, Identification and Monitoring Systems*). While the pen-picture examples are purely hypothetical and illustrative, and designed to provoke thought, rather than being predictions, the figures provided below are considered to give a broad indication of the possible benefits:

- In a new influenza emerging in 2025, a range of future DIM systems reduces UK mortality from a pandemic by ten-fold.
- In a SARS outbreak in 2015, a new diagnostic test saves £230 million of healthcare costs in an outbreak in a major city.
- In 2015, a new bio-sensor diagnostic device helps to protect UK native woodlands with an estimated value of £1–2 billion per year from diseases such as sudden oak death.
- In 2015, a hand-held diagnostic device for a range of sexually transmitted diseases saves the NHS £135 million per year for chlamydia and gonorrhoea alone. The consequential benefits of reducing HIV transmission would be much greater, at £0.5–1 billion lifetime savings for every 1,000 HIV transmissions prevented.
- In an outbreak of FMD in 2015, DIM systems virtually eliminate the need for mass culling and reduce costs of controlling the epidemic from £5 billion to £50 million. Other losses (tourism, rural trade etc.) are reduced from £3 billion to £35 million.
- In 2015, bluetongue reaches the UK. A DIM system using satellite data combined with modelling enables savings in vaccinations of £7 million.

Fig 3.2: A burning pyre during the outbreak of FMD in the UK in 2001

An African perspective on future DIM systems

The potential benefits

- Africa has the greatest burden of disease and probably the lowest level of disease management resources in the world. This implies the need for precise and effective targeting of resources, in which DIM systems could play a crucial role.
- New DIM approaches could reduce costs and make DIM devices simpler and easier to use. For example, high-tech diagnostic dipsticks could help reduce the need for highly trained personnel. Also, remote sensing from satellites coupled with disease modelling could help predict outbreaks of disease without difficult on-the-ground monitoring.
- New diagnostic devices could also make trading easier by enabling disease-free status of animals to be demonstrated on the spot.

The potential pitfalls

- There is a danger that the firms and organisations developing new DIM systems will target the diseases of most relevance to rich countries, thereby neglecting diseases of interest to Africa.
- There is also a danger that the new devices would not work in the environment in developing countries – for example, needing power or refrigeration, or trained operating staff.
- There is a substantial African concern that certain countries might sometimes use disease inappropriately as an instrument for imposing and justifying trade barriers. It would be important to ensure that the new DIM systems were not used for that purpose.

Q9 What are the most important factors influencing the effective realisation of the future DIM systems?

The new DIM systems will need to meet two key requirements:

- ***They need to be embedded in wider strategies and infrastructure for disease management, and linked to an effective response. Otherwise, the DIM information would only fuel public expectations for action and public concerns if action did not result.***
- ***The development and implementation of the DIM systems needs to be embedded within local systems of culture, governance and in public attitudes. This implies the need to adopt an interdisciplinary approach in their development and implementation – although achieving this is currently impeded by institutional and academic boundaries.***

There is a need to integrate future DIM systems effectively within the wider systems and infrastructure for disease control. For example, when a new disease outbreak is detected, it may be necessary to immediately switch on commercial vaccine production or other control strategies. This suggests the value of planning for the integration of future DIM systems at the outset. However, this is a considerable challenge as it would involve governments and public and private stakeholders operating both nationally and internationally.

There was a strong consensus from project experts that future DIM systems needed to be embedded in local systems of culture and governance if they were to be practical and effective. Indeed, issues such as ethics, public attitudes and public acceptability could be critical. However, creating interdisciplinary research programmes to achieve that would be difficult since they tend to cut across existing institutional partitions. Therefore, it would be useful for research bodies to consider how such interdisciplinary work could be better promoted.

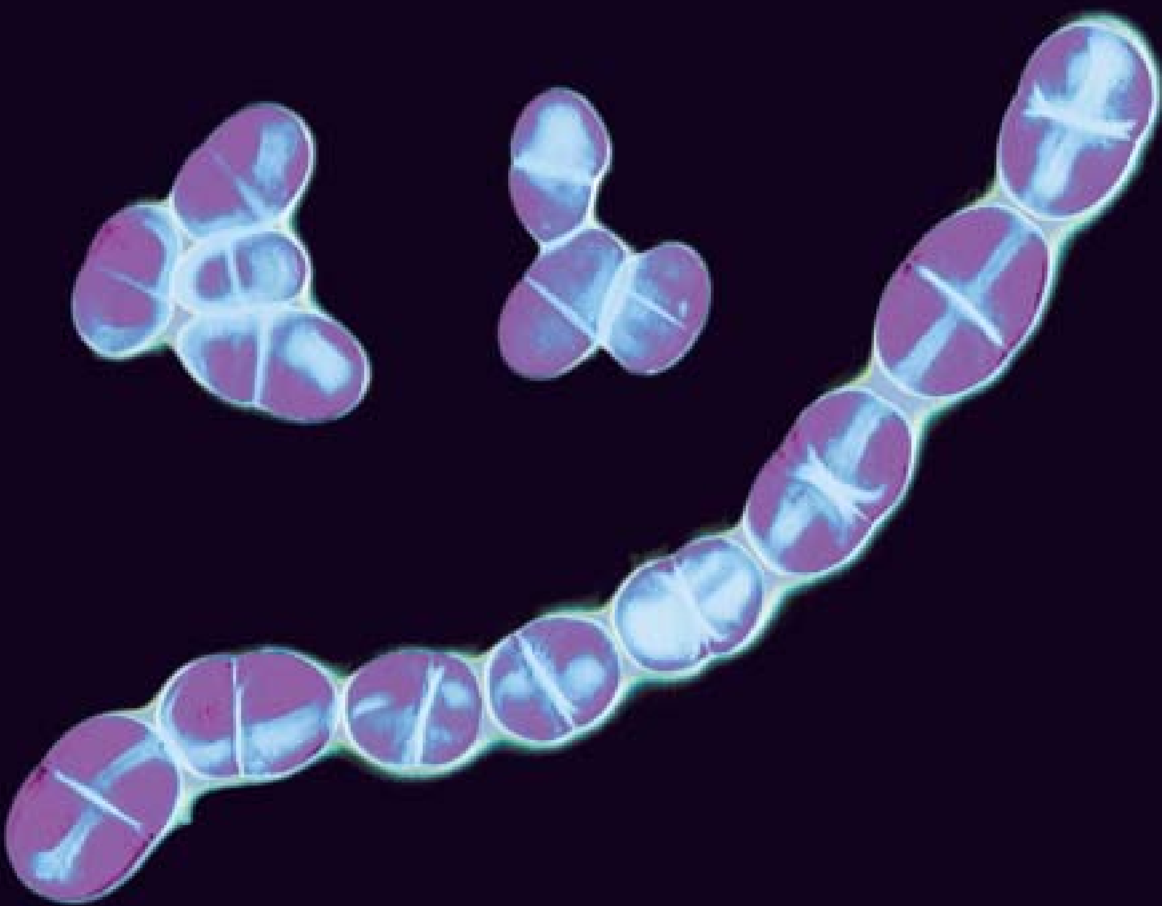
Implications of this report for counterterrorism

The DIM systems that have been analysed in this project have been considered against the threats identified in the project (see project report T1, *Future Threats*). These generally cover non-deliberate release and do not cover terrorism. Certainly such deliberate releases are important and need to be given careful consideration. However, it was considered that other bodies were better placed to make informed comment on the size and character of the terrorist threat – particularly those with access to classified intelligence.

Nevertheless, it is considered that many of the DIM systems that have been identified and analysed in this project will be broadly useful for counterterrorism. For example, a hand-held diagnostic device would work equally well on a given virus whether it has been maliciously released or not. Moreover, some of the future science and technology identified could open up new and innovative approaches.

However, it is recognised that the detailed design and implementation of the DIM systems might need to be modified to maximise their effectiveness within a counterterrorist context. For example, hand-held devices might need to look for a different set of pathogens compared with ‘normal’ use, and algorithms to detect a deliberate release (as opposed to non-deliberate) might need to be modified to account for possible differences in the pattern of release/emergence. There is therefore a case for experts concerned with counterterrorism to discuss the detailed findings of this project with key project experts with a view to examining such issues and maximising technology transfer.

4 Key choices for policy makers



4 Key choices for policy makers

There are many important issues that will affect the development of the future DIM systems, their effectiveness when implemented, and the public good that will result. These issues, in turn, imply choices for government, disease management stakeholders, and the general public. This chapter explores those choices and their implications.

4 Key choices for policy makers

The DIM systems of the future cannot be considered in isolation, but need to be viewed in the context of their use in wider systems for disease management. Therefore, at the highest level, the fundamental choices that need to be made are as much about our broad strategies for managing diseases as they are about individual DIM systems.

Q10 What strategic choices will condition future disease management and DIM systems?

Across the world, the management of diseases is predicated on three major factors. Firstly, the emphasis is on being reactive – managing existing or imminent threats. Should we be more proactive and strategic, recognising the many diverse disease threats that are expected to emerge in the future? Secondly, there is extreme disparity between disease management and DIM capabilities in different parts of the world. If we want to tackle diseases quickly wherever they arise, can we afford for this disparity to continue? Thirdly, there is a lack of coherence between disease management programmes across the world. There are many vertical programmes targeting single diseases. Should we collectively seek a more joined-up approach?

Should our strategies for managing diseases, and therefore our DIM systems, be more pro-active? We expect that diverse new diseases will emerge in the future, so it makes sense to develop flexible policies and DIM systems for managing them. This implies the need for a policy shift and taking difficult decisions – towards taking a long-term view and allocating resources for tackling future unknowns. However, stakeholders are inevitably pressurised to address immediate threats. This shifts attention and resources to the near term.

Should we aim to tackle new disease outbreaks where they emerge? It makes sense to stamp on new epidemics quickly at source. For example, modelling has shown that the emergence of a human pandemic form of influenza could only be prevented if it is detected at a very early stage and appropriate control measures quickly implemented. However, early detection of new diseases can be particularly difficult in developing countries, where there may be a lack of resources and skills. This implies the need for the international community to help developing countries to bring their DIM capabilities up to a more even international standard. This would benefit everyone.

How to achieve a more coherent approach to managing existing diseases? Vertical programmes that target a single disease have the benefit of providing a sharp focus. However, they can also result in the duplication of scarce DIM resources and existing capacity being thinly spread. Also, such vertical organisation does not sit well with the reality that many diseases interact with each other – for example, HIV/AIDS and tuberculosis – and should therefore be considered together. For DIM systems, this vertical integration can result in a costly monitoring network being set up to track a single disease (as happened initially for rinderpest in livestock and polio in humans), even though it might be cost-effective to monitor other diseases. However, moving towards a more coherent approach would constitute a major shift in policy in some donor and stakeholder organisations.

Should we make a co-ordinated, international effort to improve existing disease surveillance? While developed countries such as the UK make a significant investment in disease surveillance, there are still many gaps in our knowledge, even of human diseases. We have almost no systematic information on diseases in wild animals or plants, and limited data on diseases of livestock, pets and crops. In many parts of the world, the situation is far worse, with sparse information on even the major human diseases, and data on animal and plant diseases may be virtually non-existent. Organisations such as the World Health Organization (WHO), the Food and Agriculture Organization (FAO) and the OIE perform a great deal of valuable work in disease surveillance. We could collectively seek to build on such success and improve disease surveillance further.

Do we need a new global infrastructure? Many regions of the world do not have the laboratory infrastructure, the human resources or the financial resources to support effective disease surveillance programmes. Yet it is increasingly clear that infectious diseases are a global problem and that surveillance is an international responsibility. Investment by richer countries in surveillance capacity in poorer countries may be a sensible response to this problem.

Should we link DIM work that targets human, animal and plant diseases? Reference has already been made to the way in which human, animal and plant diseases interact to affect human health and economies. For example, today, the growth in zoonotic threats compels us to better integrate human and animal disease research and surveillance. However, responsibility for human, animal and plant health is historically segregated. Even in agriculture, animal and plant health systems are usually quite separate and take different approaches to disease risks. As a result, DIM innovation in any one of these sectors may not be shared with other sectors, despite the convergence of genomic, information and modelling science which creates common DIM technology for a range of diseases.

An illustration of the benefits of better linkages has arisen from this project. It is a new initiative in the Department for Environment, Food and Rural Affairs (Defra) to develop a 'biosecurity chip' – a disease-identification technology based on a portable microarray DNA system which will identify priority diseases of both animals and plants.

Q11 What are the choices for governance and regulation?

While there is great uncertainty in the future threats of infectious diseases, there is much that governments, policy makers and international organisations can do to prepare. Many of the key choices for governance and regulation are about recognising the need to tackle infectious diseases in a joined-up way.

How to forge better strategic linkages between the human and animal stakeholder communities? 75% of emerging and re-emerging human pathogens are also present in animals. This argues strongly for sustainable and strategic linkages to be further developed between the two communities. This is beginning to happen. For example, the WHO, the OIE and the FAO are currently seeking to co-ordinate their GLobal Early Warning (and response) Systems (GLEWS) for disease outbreaks. However, much more could usefully be done. A consistent message was the importance of high-level political encouragement.

Fig 4.1: Monitoring wild animal populations presents particular challenges

How to better address the monitoring of the wild animal reservoir? Avian Influenza (AI) illustrates the need to monitor diseases in wild animals – because they can also affect livestock, and because they can jump into humans. AI has stimulated considerable monitoring of wildfowl; however this masks underlying systemic deficiencies. Organisations such as the OIE collate data on wild animals from some countries. However, those data may lack a baseline against which they can be assessed, their collection is rarely part of an active surveillance programme and many countries do not collect such data. Improving the monitoring of wild animals would rest on three principles: making better use of existing data; focusing monitoring better; and ensuring that the mandates and resources of key organisations match the need.

How to regulate self-diagnostic devices in order to avoid the pitfalls? Consumer electronics firms are already developing hand-held diagnostic devices. These will be of value to professionals – but they raise issues about how their more widespread availability could or should be enabled and controlled in the future. There are three particularly important issues:

- It will be vital for professionals to maintain access to diagnostic information. This might be partly achieved by insisting on professional consultation for treatment, or by engineering devices to automatically relay diagnostic information by a radio link.

- People might seek to self-treat themselves or treat (or dispose of) their animals. This would act to sever patient/doctor and farmer/vet links and could undermine measures to control epidemics. It might also result in inappropriate or adulterated treatment being used – fuelling drug resistance.
- Hand-held devices will inevitably generate medical or veterinary waste. Safe disposal will be an important consideration when regulating the use of such devices.
- Provision of information, advice and support is likely to be important for those using the tests, particularly if the diseases diagnosed are serious and have substantial implications for individuals, their partners or their families.

How to improve the availability of biological specimens? Countries are sometimes reluctant to share biological specimens, either because they might jeopardise trade, or because they might themselves have commercial value. Even if countries are willing to share specimens, restrictions and regulations on the transportation and availability of biological specimens have been substantially tightened following the 9/11 attacks. This reduces the potential for their misuse, but it is important that such regulations do not over-constrain the flow of biological material, which is important for the development and testing of DIM devices.

Fig 4.2: The availability of biological specimens is vital for the development of new DIM devices

How to improve access and use of healthcare data? Sometimes, countries are also reluctant to share information on disease outbreaks since this can affect trade, tourism and have substantial knock-on effects on business. A key issue is how to incentivise countries to release such information for the common good. However, there is also a considerable amount of disease data that is already collected, but which is poorly connected. An important issue is how to promote better access to and linkages between this information so that the greatest good is attained while protecting the rights and confidentiality of individuals.

Q12 What are the choices for standards and interoperability?

Interoperability, open access and the adoption of common standards generally work to the benefit of the user/purchaser. However, they can also benefit developers by promoting the sharing of data and information, opening up markets and allowing small companies to introduce niche products. An important question is what standards would maximise the public good, and who should champion them?

Interoperability and open access: the adoption of open standards could help small firms develop diagnostic tests for diseases that are not of commercial interest to larger firms. This could help in promoting products and systems for the diseases of the developing world. For example, for hand-held devices, it would be advantageous if reagents from one manufacturer could be used with the microfluidic devices from another, or if a test from one manufacturer could function on the platform of another. Another example includes the desirability of establishing common standards for data, such as genome datasets.

Regulating the quality of hand-held diagnostic devices: this will be vital. For example, false negatives could allow the early stages of an epidemic to go unnoticed, with vital days being lost. In the case of FMD, a delay of 3–4 days could result in the doubling of the size of the epidemic (see section on validation, below).

Validation: any diagnostic device or system should be validated to show that it is fit for its purpose. Challenges will include: the collection of appropriate samples for validation (this could be particularly difficult for new or rare diseases occurring in remote regions); and the construction of sample banks linked to good clinical data.

Q13 How can we best exploit exogenous developments?

Many opportunities for developing new DIM systems will arise by taking advantage of exogenous developments – i.e. those largely unrelated to the basic drivers of managing infectious diseases. The question is how best to exploit those to maximum advantage.

Fig 4.3: Mobile phone location data is an example of personal information unconnected with healthcare

How can we maximise the public good from personal data unconnected with healthcare? A considerable amount of information currently collected for purposes not connected with healthcare could be of substantial use in modelling and managing infectious diseases. Such information might relate to mobile phone location data or the use of electronic travel cards on mass transport systems. It is suggested that key stakeholders and interested parties (such as phone operators, academics and healthcare stakeholders) be brought together to discuss how to better realise the public good from such data. Key issues already being discussed in a number of fora include data access, the protection of privacy, and personal control over the data. For health purposes, such dialogues could usefully start at the national level and then be extended internationally.

How to maximise the opportunity created by the future cheap genome sequencing technologies? Much of the development of these is driven by commercial and health needs unrelated to infectious diseases. To take full advantage will require significant advances in the basic science and investigation of infectious diseases in areas such as pathology and bioinformatics. It will also require a mix of public and private sector measures, reflecting the different sizes of potential markets for diagnostics in different types of disease.

How to maximise the public good from the drive for increasingly sophisticated hand-held devices, especially those that are networked? Major developments here are being undertaken by mobile phone companies and software providers to develop new classes of product for lifestyle and leisure users and for tackling the chronic diseases of the developed world. Taking advantage of these trends may depend on early agreement in areas such as interoperability, technical standards, data protocols, and systems of regulation and governance. There is a case to bring together mobile phone companies, diagnostic developers and disease management stakeholders to consider these issues.

How to build off systems developed for tackling terrorism, drugs, explosives and fire arms? In the future, these systems may offer the potential to help in the detection and identification of diseases, particularly at high-throughput transport nodes such as ports and airports. The issues are how to adapt the technology for DIM, and how to build the information that might be generated, into disease-management systems.

Q14 What are the key choices for Africa?

Africa is faced with the greatest burden of diseases and the lowest level of resources to manage them. Decisions taken by African policy makers today will crucially affect their ability to manage the future threat.

Should Africans take the lead in developing a new Vision and Strategy for the management of infectious diseases? Africa is beset with infectious diseases, old and new. African experts, who were involved in a project pan-African workshop in Uganda, suggested that Africans could usefully take the lead in developing a new Vision and Strategy for the management of diseases across the continent. This would be surveillance based, and supported by regional centres of excellence. The Vision and Strategy would cover diseases in humans, animals and plants, recognising that these are interlinked in complex ways, and that their detection is increasingly dependent on a common technical platform.

How best to build capacity? African experts observed that many donor organisations commission studies on Africa, either directly or indirectly, but these are too often conducted by experts outside Africa. This is demoralising for African experts and also acts as a disincentive for experts to stay in the country. If donor organisations were to decide to use more in-country experts, this could help to build capacity at no cost and would ensure that local issues and conditions were better considered.

'Smart partnerships' were widely advocated both by African experts within the project, and international organisations as a means to build and maintain capacity. These would involve experts and organisations from African and developed countries; they would promote the sharing of information and expertise and could also help to ensure that new DIM systems were relevant to the continent.

Fig 4.4: Smart partnerships offer an opportunity to build and maintain capacity

How to ensure that African politicians have the best information to justify the allocation of resources? Claims for resources to manage infectious diseases must compete alongside many others. The African experts considered that there was a need for better information to inform politicians of the needs and benefits of supporting better disease management, including DIM.

How to ensure that infectious diseases are taken into account in the development of other policies? In the case of regionalisation, for example, removing trade restrictions on seed within the East Africa Community could make the control of diseases more difficult and create the need for counterbalancing measures.

How to ensure that DIM systems are linked to effective follow-on treatment? This is critical since, without effective treatment, expenditure on the DIM systems would have limited value. There is no easy answer to this. However, the problem underlines the need to embed the deployment of any future DIM systems firmly within integrated strategies for disease control.

Q15 What are the implications for science?

Understanding the future risks of infectious diseases, and how best to use DIM to help manage those risks is an interdisciplinary problem. A key challenge is to bring together relevant skills expertise to deliver properly integrated scientific research and development and to provide suitable opportunities for capacity building.

Removing intellectual barriers: we need a science base that will deliver DIM technologies and systems that are both generic and flexible. This means that traditional divides – e.g. between virology, bacteriology, mycology and parasitology, or between medicine, veterinary medicine and plant science – need to be bridged. Similarly, the science base underlying DIM technologies needs to advance alongside social science research concerning the effective deployment of DIM systems.

Key drivers are mostly not biological: future infectious disease risks will be determined by a complex multitude of factors such as human demography and behaviour, land use and agriculture, travel and trade, climate, social trends and economics, governance systems, disease control policies, public attitudes, natural disasters and (conceivably) bioterrorism. Analysing past, current and future trends in each of these drivers is a formidable task in its own right.

A broad knowledge base is essential: we still have only a sketchy understanding of the relationship between the key drivers and infectious disease burdens. Further advances will require moving beyond the traditional confines of epidemiological research to embrace a wide range of other disciplines such as anthropology, economics and climatology.

Data on disease emergence: one route to a better understanding of future disease risks is a better understanding of past and present examples of the emergence and spread of infectious diseases. Collation and critical analysis of such data could provide valuable information. Every new outbreak provides valuable data for research, if appropriate efforts are made to capture it and to make it available.

Improved modelling capacity: mathematical approaches are increasingly being used to assess current and future disease risks as aids in the design of intervention strategies and as a source of advice to policy makers. Further development of statistical, computational and mathematical tools is required, especially on the linkage between models and data. A better understanding of these approaches within the wider community would help ensure that mathematical models are used to best effect.

Q16 What are the implications for technology and systems?

How DIM technology is used is just as important as the technology itself, and considerable benefits are foreseen from improving the systems in which the technology operates.

Better technologies: some relatively new technologies need further development. For example, technologies to distinguish vaccinated individuals and animals from those exposed to infection need to be developed for real-time application in the field. Better diagnostic testing for pre-clinical and sub-clinical infections would greatly assist the management of epidemics.

New technologies: research and development is still mainly directed at diagnosing specific infections in individuals. It would be useful to develop tools for testing for a number of different infectious agents at the same time and tools for screening large numbers of individuals based on non-specific responses to infection. There may be synergies between different approaches to diagnostics – e.g. between genomic and immunology-based technologies – which could be exploited in a single device.

Technology integration: advances in individual technologies – such as data capture, genomics-based diagnostics, smart swabs or high-throughput screening – are of limited value in isolation. The integration of technologies, such as combining hand-held diagnostic devices with wireless internet links, could deliver much more powerful tools.

Design of surveillance systems: the science of designing disease surveillance systems to detect unusual disease events or to identify at-risk populations is relatively underdeveloped. Modern computational and modelling approaches could be used to address this issue.

Health systems research: we need to understand how new DIM technologies can be used most effectively, and how to promote their use as part of systems for managing human, animal or plant diseases. This would include more detailed study of the needs, expectations, capabilities and sensitivities of the end users and other stakeholders.

Q17 What are the implications for skills?

> ***The tasks of identifying future disease risks and developing and deploying DIM technologies to help manage those risks are inherently interdisciplinary. We need individuals with specialist skills and, importantly, with combinations of different skills if we are to meet the challenge.***

Skill sets: traditional training in science and technology does not deliver the range of skills necessary to tackle the breadth of issues relevant to assessing and managing infectious disease risks. Interdisciplinary approaches to training, more opportunities for scientists and technologists to broaden their skill set at any stage of their careers, and international exchanges of knowledge and expertise would all help to address this problem.

Maintaining expertise: the erosion of expertise in key disciplines threatens our ability to maintain infrastructural competence and surveillance – all the more so in developing countries. New technologies, ‘smart partnerships’, centres of excellence and international fellowships for collaborative study could provide much-needed integration and sustainability.

Communication skills: a key aspect of interdisciplinary working is good communication. This applies at every level: scientists with scientists in different disciplines (including social sciences and the humanities); scientists with technologists; scientists with policy makers and other stakeholders. Greater emphasis on communication skills at every career stage, including direct experience of communicating across disciplines, would facilitate more effective interactions.

Q18 What are the implications for public engagement?

The public will need to weigh the 'costs' of some future DIM systems (e.g. concerning civil liberties) against the benefits the systems will bring (e.g. reduced risk from disease). Public engagement with these issues will be a precondition for ensuring the effective design of such systems.

For example:

- Where DIM systems use personal data, the public will need to be convinced that its collection and use in monitoring systems is necessary, and that desired confidentiality will be maintained. For example, the use of trusted bodies could usefully be considered as a gateway for particularly sensitive data (to ensure personal information is not passed on).
- Hand-held diagnostic devices (UC3) offer considerable scope for inappropriate use. As they become more widely available, nationally and internationally, it will be essential to engage with potential users to develop systems that support the use of devices and reagents only from reputable sources. It will also be important to ensure that users are supported with professional advice to enable them to use the devices safely and to take the appropriate actions in response to the diagnoses they obtain.
- High-throughput screening, for example at ports and airports, presents particular sensitivities. Any future systems would need to take careful account of the needs and concerns of the wide range of travellers and operators that might be affected.

Q19 What are the next steps?

A report of this breadth cannot provide detailed answers to the complex problems of managing the vast multitude of diseases in countries across the world. It has not set out to do that, but rather to provide signposts to how the threat may evolve and where policy development could usefully be considered.

Nor does the project seek to tell stakeholders what they should or must do. Rather, its findings are provided for policy makers and stakeholders to consider and to interpret within the context of their own situation and their own policy development processes.

A number of important stakeholders have already announced actions that will be taken following the launch of the findings. These may be found in the *Action Plan* (project report P1). The OSI welcomes these developments and others that are being considered elsewhere.

Appendix A

Experts involved in the work

The Office of Science and Innovation would like to acknowledge and thank the members of the project's Science Co-ordination Group, the leaders of the Risk Evaluation work, the High-level Stakeholder Group, the Expert Advisory Group and the many other individuals listed below who contributed to the work.

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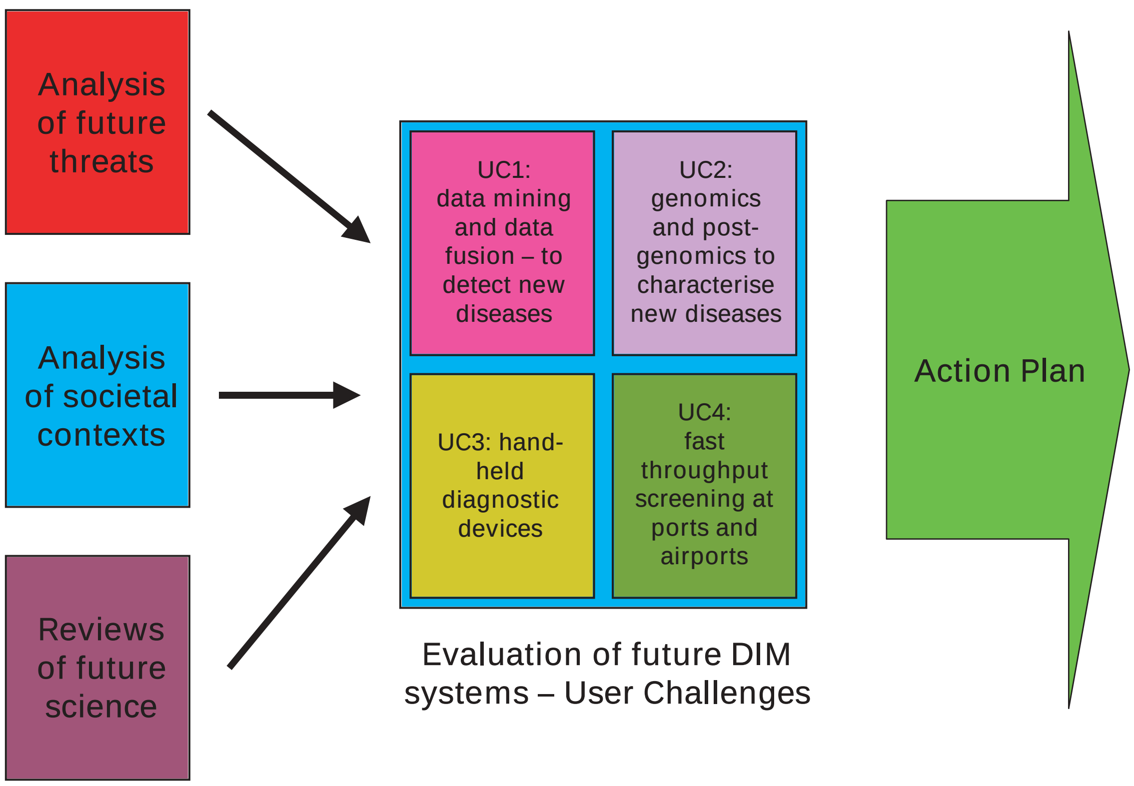
Appendix B

Details of the work performed in the project

The main parts of the project are set out in Figure B1 and are described below. The reader wishing to find out more about each of these aspects should begin with the project reports indicated in brackets. A chart of all project reports and supporting papers is provided in Appendix C.

Fig B1: The key parts of the project



Analysis of future threats (T1): a starting point was to generate a vision for the future threats of infectious diseases and the factors driving them. This defines the challenge facing stakeholders, and the requirements for future DIM systems. T1 provides an overview of the findings which drew on: expert surveys in UK, Africa and China; reviews of existing and new diseases; analysis of the future effect of climate change on diseases; and the effect of diseases on ecosystems.

Analysis of societal contexts (D4): the effectiveness of future DIM systems will crucially depend on their sensitive deployment within different systems of culture and governance, as well as local systems of belief and attitudes. These issues have been explored in several studies.

Reviews of future science (S1): reviews of the state of the art were performed in ten diverse areas of science. These will form the building blocks for new and innovative DIM systems of the future. They ranged from Earth observation to genomics, and data processing to immunological techniques.

Evaluation of future DIM systems (D1): four classes of future DIM systems (User Challenges) were identified for detailed analysis (see Figure A1). The analysis of these considered their costs and benefits against examples of future disease threats. Roadmaps for their realisation were also produced, taking account of barriers and enablers, as well as the societal contexts.

Action plan (P1): all of the above work has led to the development of a detailed action plan by key stakeholders around the world.

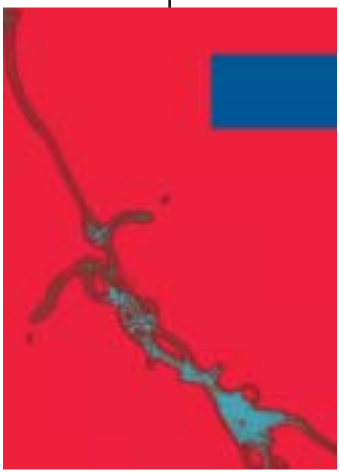
Finally, because Africa was a key geographical focus for the project, all the Africa-related strands of the project are drawn together in report A1, *Africa*.

Appendix C

Structure of the project reports and supporting papers

E1: Executive Summary

S1: Science Review Summaries



T1: Future Threats

Detailed reviews of science:

S3: Intelligent sensor networks
S4: Data mining and data fusion
S5: Non-invasive screening and scanning
S6: Genomics and bioinformatics
S7: Biosensors and biomarkers
S8: Interrogation of natural signals
S9: Predictive and real-time epidemiology
S10: Earth observation
S11: Host genetics and engineering
S12: Immunological techniques

Risk analysis:

T2: Risk analysis
T3: Expert survey of the UK and Africa

Disease case studies:

T5.1: MRSA
T5.2: HIV/AIDS
T5.3: Influenza in humans
T5.5: Food-borne pathogens
T5.6: Fish diseases
T5.7: Potato late blight
T5.8: Malaria
T5.9: Rinderpest
T5.10: Plant viruses in sub-Saharan Africa (SSA)
T5.11: Sudden oak death
T5.12: West Nile virus

Climate change:

T7.1: Overview
T7.2: Plant diseases
T7.3: Animal diseases
T7.4: Human diseases

Modelling reviews:

T8.1 Overview
T8.2: Malaria in SSA
T8.3: Bluetongue in Europe
T8.4: TB control in SSA
T8.5: Global traffic
T8.6: Foot-and-mouth disease (FMD)
T8.7: Paediatric HIV/AIDS
T8.8: Tsetse in SSA
T8.10: Malaria UK
T8.11: Eco-costs of potato ring rot

NOTE: Report numbers are not sequential.
Some report numbers were originally reserved for reports which were subsequently not commissioned.

A1: Africa

D1: Vision of Future Detection, Identification and Monitoring Systems

P1: Action Plan

Further reviews and research:

- T9: Review of initiatives
- T10: Travel and migration and their impacts on diseases
- T11: Effects of diseases on ecosystems
- T12: Wildlife trade
- T13: China – human and zoonotic diseases
- T15: Plant pathogen database analysis
- T16: Human pathogen database analysis

Africa papers:

- A3.1 Paper for the Commission for Africa (CfA)
- A3.2 CfA paper appendices
- A4: Report of a pan-African workshop
- A5: Report of a pan-African workshop (French)

User Challenge work:

- D2: Introduction to the User Challenge work
- D2.1: UC1 – Data mining and data fusion
- D2.2: UC2 – Genomics and post-genomics for characterising new pathogens
- D2.3: UC3 – Hand-held diagnostic devices
- D2.4: UC4 – Fast-throughput screening devices

Future control of diseases:

- D3.1: Plant diseases
- D3.2: Animal diseases
- D3.3: Human diseases

Culture and governance:

- D4.1: Plants
- D4.2: Animals
- D4.3: Humans

- D5: Historical perspectives
- D7: Public perceptions of risk

About Foresight

This project is one of a number of projects within the Office of Science and Innovation's Foresight programme. The aim of Foresight is to produce challenging visions of the future in order to ensure effective strategies now.

Six Foresight projects have now been completed, and details of each may be found on www.foresight.gov.uk. Examples include:

- **Cognitive Systems:** looked at developments in the physical and life sciences concerning thinking systems. The objective was to bring the two communities together to share their knowledge and perspectives. The project explored emerging and future technologies, for a wide range of applications in fields such as transport, defence and leisure.
- **Future Flooding:** developed a cross-disciplinary model for flood and coastal erosion risk during the twenty-first century. It developed a range of scenarios for the potential impacts of climate and socio-economic change.
- **Brain Science, Addiction and Drugs:** considered how we might manage the use of psychoactive substances for the benefit of individuals, communities and society in 2025. It explored what those substances might be in the future, what their effects might be, and what methods we might have for managing their use.

Foresight has recently started its eighth project:

- **Tackling Obesities:** looking at the risk factors affecting different types of obesity; the implications of obesity for the individual and society, and options for managing those challenges.

OSI Horizon Scanning Centre

The Horizon Scanning Centre (HSC) undertakes central strategic scanning for future opportunities, risks, and developments across Government, helping Government departments explore the implications of emerging trends and issues identified in its Sigma Scan (full public policy spectrum) and Delta Scan (science & technology). The HSC also supports departments in their own horizon scanning activities through a programme of coaching and workshops. Further information can be found at on: www.foresight.co.uk/horizonscanning

Details of all the reports and papers produced within this Foresight project can be obtained from the Foresight website (www.foresight.gov.uk). Any queries may also be directed through this website. The reports and outputs of the project should not be taken to represent the policies of any governments or organisations involved in the work.

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