EXECUTIVE SUMMARY

There is, in Great Britain, a mature and well-established system for controlling the risks to workers and the public arising from work activities, underpinned by legislation and by both international and domestic standards. This system is comprehensive and is flexible enough to deal with new risks and hazards, achieving sensible risk management. It is a system that has allowed Britain to benefit from levels of public and worker safety that are comparable with the best in the world and achieve high levels of public confidence as measured by opinion surveys. The system is based on a set of general requirements in health and safety at work law (discussed in chapter 1) that apply to all the energy developments considered in this report, supported by specific provisions that apply to the particular developments that are described in chapters 2 to 7.

One of the most important features of this system of health and safety at work law is its flexibility. Because of the underpinning provided by the general duties, any new technology that develops (such as the new and anticipated technologies related to carbon capture discussed in chapter 3) is immediately subject to legal requirements on those working with it to achieve acceptable standards of safety. Specific new regulatory controls are not needed, though these may follow (for example, to impose a 'permissioning' regime to require some form of approval from a competent body before an activity starts) if the risks are sufficient to merit such action.

Against this general background, conclusions on the specific energy developments the Energy Minister asked be examined (see *Introduction* and Annex 1 for an explanation of the remit) are as follows.

Gas storage

The hazards and risks of the land-based aspects of liquefied natural gas (LNG) import and storage facilities and of storage of natural gas in salt cavities and strata, onshore and offshore, are well understood.

Effective safety standards, including technical standards and management systems, have developed to ensure that the risks from future developments can be managed sensibly.

The existing regulatory strategy for ensuring the risks are properly controlled is robust, with no significant gaps in legislation, though there is a need to review the suitability of some parts of the current legal framework (see chapter 8, paragraph 428). There are mature systems and resources for dealing with these facilities. The existing approach is sufficiently flexible to allow the technology to develop while maintaining safety standards.

Carbon capture and storage

Carbon capture and storage technologies (CCS) provide a challenging opportunity for mitigating the effects of the use of fossil fuels on atmospheric carbon dioxide (CO_2)

levels. These projects will be major undertakings that will involve new technology.

Advances will be underpinned by existing relevant experience, knowledge and understanding. Consequently, the risks to safety from the deployment of CCS are acceptable, but the limitations of current knowledge and the areas highlighted below will need to be recognised and addressed. These can be divided into three groups of issues, relating to research, standards, and the existing safety regulatory framework.

First, on research and knowledge needs, the most significant area of uncertainty and concern associated with CCS is centred on the properties and behaviour of supercritical or dense phase carbon dioxide. In particular, the lack of large-scale experimental data and the failure of existing modelling techniques to handle the complexity of its behaviour following a leak or other loss of containment event need to be addressed.

The ability to anticipate foreseeable accident scenarios and accurately predict the consequences of these hazardous events is a fundamental element in the assessment of risk, the management of health and safety and the appropriate regulation of hazardous installations. Duty holders have at present an incomplete capability to predict accurately the consequences of a major loss of containment event involving dense phase carbon dioxide. This incomplete understanding and capability needs to be addressed. New models, methodologies and underpinning skills to perform the necessary assessments are needed to assess risks when CCS installations are proposed. This is best done through appropriate-scale experimental work that will provide the basis from which suitably sophisticated models and methodologies can be constructed. The responsibility for addressing these needs rests squarely with industry – those who will be responsible for the risks but who will benefit from the technology. However, there would be mutual benefit if the regulatory bodies, duty holders and key stakeholders worked together to identify what is needed. Research is required to develop a shared capability regarding the understanding of release behaviour.

It is foreseeable that, in future CCS installations, the carbon dioxide injection pressures may be significantly greater than those in enhanced oil recovery (EOR) operations and current CCS projects. The resulting challenges to existing materials technology and operating procedures should be identified and resolved through appropriate research and development programmes, and the new knowledge promulgated.

Second, in relation to standards, although there are applicable general engineering standards, the lack of internationally recognised standards and codes of practice specifically for dense phase CO_2 plant and equipment is a handicap to the adoption of a consistent approach to safety related engineering issues. There is a need for the industry and other key stakeholders, such as the British Standards Institution (BSI) and International Organisation for Standardisation (ISO), to work together to address this important issue. Although the responsibility rests squarely with the industry, the Health and Safety Executive (HSE) will seek to facilitate progress.

Third, the current regulatory framework predates the concept of large-scale CCS but provides a sound basis for the appropriate regulation of most aspects of these activities on and offshore, particularly in respect of the general management of health and safety, the established technology areas of major hazard sites, and occupational hygiene.

The prospect of transporting or injecting very large quantities of carbon dioxide was not envisaged when the regulatory framework for controlling the risk from hazardous installations was drafted. Consequently, the presence of carbon dioxide does not, by itself, trigger any of the major hazard legislation. The information currently available gives some cause for concern regarding its major accident potential, and this will be examined in detail in appropriate research programmes. If concerns are confirmed, consideration will be given to the need to strengthen current regulatory arrangements. Consideration will also need to be given to regulatory issues related to long-term responsibility for carbon dioxide storage sites once injection operations have been completed and the well has been sealed off.

Renewable energy sources: Wind, wave and tidal power

The risks to those who work in the onshore and offshore wind energy industries are adequately covered by existing health and safety legislation. There remains a need for adequate guidelines for planning authorities to address risks to members of the public. HSE will continue work with all relevant parties to facilitate the production and maintenance of such guidelines.

Renewable energy sources: Biomass

Biomass can be considered as a form of stored solar energy. The sun’s energy is ‘captured’ through the process of photosynthesis in growing plants and thus by the animals in the ‘food chain’ that eat these plants. ‘Biomass’ is a generic term covering virgin material (such as crops and forestry), recycled clean biomass and waste material from municipal and commercial sources (sewage, and food and animal wastes).

None of the biomass energy production processes are particularly novel and their expanded use would not require a change to current regulatory arrangements or strategy. There are, however, training and familiarisation issues that arise as the current generation of process engineers, including those in industry and in regulatory bodies, have been more familiar with the utilisation of fossil resources for energy needs.

Distributed generation

Distributed generation is the name given to power generation at or close to the consumer. The fuel and technologies used for such generation are many and varied. The four main technologies used in distributed generation are external combustion engines, internal combustion engines, gas turbines and fuel cells running on natural gas, liquefied petroleum gas (LPG), fuel oil, hydrogen, hydrocarbon or methanol fuels. Many are operated in combined heat and power (CHP) configurations (a highly fuel-efficient energy technology where heat and power are produced simultaneously).

Distributed generation, and the ‘hydrogen economy’, will involve either new technology or established technology operating in novel situations, frequently retrofitted into environments that are characterised by low user skill levels. These environments are often more difficult to regulate and responsibilities are often less well defined, creating a need for attention to communication and education of installers and domestic users. However, current regulatory controls require the workforce to have an adequate level of competence, including in relation to gas work.

The existing framework of regulatory provisions, codes and standards provides a strong basis to ensure that workers and the general public are not exposed to unacceptable risk, while ensuring that the framework is not unnecessarily burdensome to the deployment of distributed generation and hydrogen economy devices in these new environments.

None of these technologies involves risks of a different category or magnitude from those already found in many workplaces and homes, and existing risk control measures can adequately control these risks. However, the inherently decentralised approach of distributed generation will create a need to ensure that the responsibilities and skill levels in the industry and in the different organisations involved in regulatory arrangements (including, for example, the fire service) are kept under review.

The generation of electricity by nuclear power stations

The design of nuclear power stations continues to evolve. For the purposes of this report, we assume that proposals for new construction of new nuclear power stations in the UK would utilise what are described as Generation III (or III+) designs. These power stations will generally have some or all of the following characteristics:

- a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time;
- a simpler and more rugged design, making them easier to operate and less vulnerable to internal (fire, flood) and external (earthquake, aircraft impact) hazards;
- higher availability and longer operating life – typically 60 years;
- greater use of passive safety systems, inherently safe design features, or more diverse, segregated and redundant plant;
- reduced risk of core melt accidents;
- minimal effect on the environment;
- higher fuel burn-up to reduce amount of fuel used and the amount of waste.

From the safety viewpoint, therefore, vendors claim a reduction in risk compared with the older designs. While HSE cannot agree with these claims in advance of our safety assessments, our expectation is that third generation reactor systems will demonstrate appropriate levels of safety with risks no greater than those of existing reactors, and there are therefore no reasons in principle why such reactors cannot be safely operated within the current UK regulatory framework.

The health and safety risks that principally concern the public are those relating to the release of radioactivity. There are specific measures taken to restrict the exposure of workers and the public to ionising radiation during normal operation. It appears likely that the average radiation doses to workers and the public to ionising radiation from Generation III reactors during normal operation will be no higher than the best standards currently achieved, and thus acceptably low. This assumption would be rigorously checked during the assessment process. Any new reactor design would also be rigorously checked to ensure an acceptably low level of risk of releases of radioactivity due to accidents. The history of nuclear accidents has led to safety improvements and before licensing any new nuclear power stations, the Nuclear Installations Inspectorate (NII) (part of HSE's Nuclear Safety Directorate) would require a demonstration that the potential for accidents was robustly protected against.

Regulatory control is achieved by a comprehensive and well-tested framework of legislation governing the health and safety of the nuclear industry. The system of regulation is based on requirements for nuclear site licences and conditions associated with the granting of these licences, backed up by exacting assessment, inspection and enforcement arrangements. The Nuclear Installations Act 1965, as amended, allows HSE at any time to attach such conditions as appear to it to be necessary or desirable in the interests of safety, and in respect of the handling, treatment and disposal of nuclear matter. These conditions cover safety-related functions including:

- marking the site boundary;
- the appointment of ‘suitably qualified and experienced persons’ to perform any duties which may affect the safety of operations on the site;
- the production of adequate safety cases for all operations affecting the site and the preservation of records;
- the handling and storage of nuclear material;
- incident reporting and emergency arrangements;
- design, modifications, operation and maintenance;
- control, supervision and training of staff;
- decommissioning arrangements and programmes; and
- control of organisational change.

Licensees are required to make a written submission concerning safety arrangements, referred to as the safety case. The licence conditions and the safety management system described in the safety case are monitored by NII through a robust system of inspection and enforcement.

It is the responsibility of the licensee (or licence applicant) to provide a comprehensive demonstration (a safety case) that safety will be properly controlled through all stages of the plant’s life. NII takes a holistic ‘whole life’ approach. It therefore expects the safety submission to cover not only the design, but also aspects such as construction, maintenance, operation, radioactive waste and decommissioning. Although the format for safety cases is not prescribed, HSE has published Safety Assessment Principles (SAPs) against which it assesses the adequacy of licensees’ safety cases.

NII’s methodologies have been subject to searching independent scrutiny. The SAPs were the subject of consultation within the industry and, for the development of the

HSE's *Tolerability of risk* document, a formal public consultation was carried out. The Nuclear Safety Advisory Committee (NuSAC) advises the Health and Safety Commission (HSC) independently on nuclear safety issues, including for example on the nuclear safety issues arising from this energy review, and the committee often seeks evidence from NII.

Construction of a new nuclear power station would not be allowed to commence until a Nuclear Site Licence has been granted. NII will not grant a Licence unless it is content with the proposed reactor design, the site location, and the licensee's organisation. To be satisfied with the design, NII would require an acceptable safety submission.

While there are no significant changes required in the legal provisions relating to the development of a further generation nuclear power stations, there will continue to be evolution in administrative processes. HSE is considering further developing the arrangements for pre-licensing assessment of candidate designs, as set out in Annex 2.

A multi-stage assessment and licensing process is under consideration. Phase One would be a design acceptance process with four components:

- Step 1: design and safety case submission based on generic principles;
- Step 2: a fundamental safety overview;
- Step 3: an overall design safety review;
- Step 4: detailed design authorisation assessment.

Phase Two is site and operator specific and is HSE's assessment on which to base the granting of a nuclear site licence. This involves assessment of the plant, the site and the operating organisation. While Phase One may have a duration in the order of three years if various conditions are satisfactorily addressed, Phase Two may take approximately six to twelve months if the applicant provides a detailed and adequate submission and other permissions (for example planning, Electricity Act) are forthcoming. This process is intended to provide a transparent, rigorous and robust regulatory approach to the safety of any new nuclear reactor build, reflecting the various views of our stakeholders and our commitment to being an open and accountable regulator.

Our overall conclusion is that there is a well-established regulatory framework for the UK nuclear power industry and, since this has been in place, there has been a good safety record. This framework has been vindicated in public inquiries and has been subject to peer review by international experts.

NII has satisfactorily regulated nuclear reactors of 'first' and 'second' generation designs. Generation III reactors will be an evolutionary design making use of proven technology and operating experience, benefiting from modern safety analysis techniques and philosophies. It is therefore expected that licence applicants could demonstrate appropriate levels of safety with risks no greater than those of existing reactors, and there are no reasons in principle why such reactors cannot be safely operated within the current regulatory framework. However, for NII to play fully its part in future regulatory arrangements it will need to be appropriately resourced.

Cleaner coal technologies (CCTs)

Cleaner coal combustion technologies are refinements and developments of mature techniques. Their deployment will be underpinned by existing relevant operational experience, knowledge and understanding. Consequently, the risks to safety from their use are acceptable.

While existing regulatory controls are sufficient to provide a framework for the acceptable control of risk, the following should be noted:

- attention needs to be paid to what is currently a lack of experience related to supercritical steam plant;
- the use of underground gasification technology will require continuing attention. The extent of the potential hazards, the difficulty in controlling and monitoring the operation deep underground, and the lack of first-hand operational experience and reliable information mean that the acceptability of the risks involved in this process need to be kept under review. The participation of industry and regulatory bodies in international research and demonstration projects is essential, and is likely to be an effective way in which duty holders and regulators can jointly develop their understanding;
- with regard to coal bed methane extraction, there is a need for further information on the risk profile presented by the use of carbon dioxide to enhance methane recovery;
- there is a need to monitor the behaviour of new materials used in above-ground CCTs, and maintenance and inspection regimes should be appropriately designed. Such issues arise, in particular, in respect of the materials used in gasification equipment, where the nature of the process means that plant items will require frequent disassembly and aggressive cleaning. The implications of these issues will need to be anticipated, which, in view of the limited amount of recent experience, mean that a cautious approach is required;
- the development and wider use of these technologies will create a need for both industry and regulatory bodies to develop and maintain appropriate competence, particularly in the field of mechanical engineering.

Future requirements

The risks related to the new energy developments discussed in this report fall broadly into three categories:

- there are conventional occupational health and safety risks, which are either already well understood and adequately controlled or able to achieve that position with minimal additional research and development;
- there are 'acute' major accident risks of substantial but limited consequences (such as fires, explosions or the release of toxic gases) where the likelihood of occurrence is very low and well controlled or, where the energy development involves new technology, there is reasonable confidence that it will remain

low provided identifiable research and development work is carried out successfully;
- there are very low probability but high-consequence major accident and widespread chronic ill-health risks, for example from nuclear power generation, which require highly specific regulatory controls.

While these risks are, overall, capable of being well controlled, there are a number of general factors that must be the subject of continual attention if overall safety levels are to be maintained as the new energy developments considered in this report are further exploited. These are discussed in chapter 8.

First, the skills base (in relation to these technologies) of those who work in the organisations involved (the ‘duty holders’ under health and safety at work law) and in regulatory organisations must be maintained. This requires continual attention to reviewing the technology, to the assessment of competence, and to training. Second, the overall framework of control needs to be kept under continuing review by regulatory organisations. Third, where we have identified further research needs, this research must be properly conducted. It is not the job of HSE, nor of Government in general, to conduct such research – the responsibility rests firmly with the industries involved. There is, however, a responsibility on the organisations that exercise regulatory oversight to facilitate and assist where necessary.

The analysis of the risks and hazards associated with the new energy developments reviewed in this report, both those involving new technology and those involving the much wider application of existing technology, suggests that the existing framework of control is generally adequate, but we have identified a number of areas where a more specific review of current arrangements is required. These are detailed in chapter 8. The urgency and priority that attaches to these areas for further consideration, and the resourcing consequences for HSE, will depend on the decisions the Government takes at the conclusion of the energy review. HSE will further examine what is needed, to what timetable, in the light of those decisions. None of the areas for further review summarised in chapter 8 requires urgent action today, but it is essential that HSE remains closely involved with the planning activities across Government necessary to take forward the conclusions of the energy review so that the required action can be taken to the appropriate timetable.

INTRODUCTION: THE HEALTH AND SAFETY EXECUTIVE'S REMIT AND CONTRIBUTION TO THE REVIEW

1 The Department of Trade and Industry (DTI) launched, on 23 January 2006, a consultation exercise in support of the Government's energy review, announced on 29 November 2005. The consultation document (*Our energy challenge – Securing clean, affordable energy for the long term* DTI January 2006) stated on page 15:

> 'As part of its role in monitoring health and safety in many areas of the energy sector, the Government will be calling on the Health and Safety Executive (HSE) to provide an expert report during the course of the Review. This is necessary for the Government to make informed decisions in bringing forward future proposals.
>
> 'The Government have requested that the HSE report on some specific potential health and safety risks arising from recent and potential energy developments and on the HSE's approach to ensure that risks arising from these are sensibly managed by industry, including:
>
> - an increasing need for gas storage in the UK;
> - new demonstration projects for carbon capture and storage, and its potential in the UK;
> - increasing penetration of renewables and distributed generation in the UK;
> - consideration of a new generation of nuclear power stations and in the event of nuclear build, the potential role of pre-licensing assessments of candidate designs.'

2 More detail on what the Government wanted HSE to contribute to the Review was contained in a letter from the Energy Minister, Malcolm Wicks MP, to the Chief Executive of the HSE, Geoffrey Podger, on 10 January 2006. The full text of this letter is included at Annex 1 to this report.

3 This report is HSE's response. The report begins with a general statement of HSE's approach to regulation of health and safety at work (chapter 1) and then deals individually with the recent and potential energy developments that the Government asked us to review. In addition, we have included a chapter (chapter 7) on cleaner coal technologies, which are a significant new area in health and safety terms and are also mentioned in the commissioning letter at Annex 1. The chapter on renewables (chapter 4) concentrates on those presenting significant risks. The report does not cover existing mature energy sectors (such as coal extraction and offshore oil and gas production) where health and safety controls are well established. Nevertheless, decisions about the future of such mature sectors (such as extending the production life of offshore infrastructure) also need to take account of the health and safety implications.

4 The energy developments the report deals with are varied – some concern energy production, some storage and some energy processing. Consequently the structure of each chapter varies, though each covers the same ground – an overview of the technology, the applicable standards, the health and safety risks and the regulatory

strategy. The report starts (chapter 1) with a general statement of the regulatory approach that applies to all of these energy developments.