

THE HEALTH AND SAFETY RISKS AND REGULATORY STRATEGY RELATED TO ENERGY DEVELOPMENTS

An expert report by the Health and Safety Executive contributing to the
Government's Energy Review, 2006

28 June 2006

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From the Chief Executive

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Dear Minister,

THE 2006 ENERGY REVIEW: HSE EXPERT REPORT

You wrote to me on 10 January, in the context of the Government's Energy Review, requesting an expert report on the potential risks relating to health and safety at work that might arise from some specific energy developments that are being assessed as part of the review.

We were pleased to receive this commission. I now enclose our response, submitted ahead of your 30 June deadline.

In our report we identify some actions that may be needed depending on the outcome of the Government's review. The analysis of the risks and hazards associated with the new energy developments reviewed in our report, both those involving new technology and those involving the much wider application of existing technology, suggests that the existing framework of controls is adequate. However, we have identified a number of areas where a more specific review of current arrangements is required. 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 review.

We are publishing our report today. I am copying this letter and our report to the other recipients of your 10 January letter.

*Yours sincerely,
Geoffrey Podger*

GEOFFREY PODGER
Chief Executive

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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 (CO₂)

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 CO₂ 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.

1 THE HEALTH AND SAFETY EXECUTIVE'S REGULATORY APPROACH

5 Before turning to the specific energy developments on which HSE has been asked to provide advice, this chapter describes our general approach to achieving acceptable standards of health and safety at work, something that we regard as a cornerstone of a civilised society. This general approach has as its objective the acceptable control of risks to workers and the public arising from work activities, and forms a backcloth to the regulatory arrangements to deal with the specific issues described in later chapters.

The role of the Commission and Executive

6 The Health and Safety Commission (HSC) and the Health and Safety Executive (HSE) are non-Departmental bodies with specific statutory functions in relation to health and safety at work. As such, they are responsible for the regulation of almost all of the risks to health and safety arising from work activity in Great Britain.

7 The Commission includes members representing employers, employees and the local authorities (who, along with Ministers and the general public, are the principal stakeholders in occupational health and safety) and others, including an appointee to represent the public interest. HSC's role is to conduct and sponsor research; promote training; provide an information and advisory service; and submit proposals to Ministers for new or revised regulations and approved codes of practice.

8 HSE aids the Commission in its role, in particular by monitoring new or developing hazards and identifying areas where policy or legal requirements need to be changed or strengthened. HSE strives to be open and transparent in all that it does. HSE is also responsible for enforcing health and safety at work legislation in many workplaces (enforcement is carried out by local authority inspectors in some workplaces, for example, shops, office buildings).

Health and safety at work law

9 The body of health and safety at work law that HSE enforces is primarily the Health and Safety at Work etc Act 1974 (HSW Act), and specific regulations under the 1974 Act, to deal with areas where more specific controls are needed. This Act marked a fundamental change in the approach to workplace health and safety, replacing prescriptive legislation such as the Factories Act with legislation that in many cases set goals for duty holders, but left them to decide for themselves the means by which the goals should be achieved. The HSW Act is augmented by regulations dealing with specific aspects of occupational health and safety (for example, the Control of Substances Hazardous to Health Regulations 2002, Ionising Radiations Regulations 1999, Provision and Use of Work Equipment Regulations 1998, Control of Asbestos at Work Regulations 2002), many of which were enacted in response to European Directives. It is also augmented by statutory provisions from enactments existing in 1974 and not subsequently repealed, such as some schedules of

the Nuclear Installations Act 1965. Regulations are sometimes supported by Approved Codes of Practice (ACOPs), which have a special status in law under section 16 of the HSW Act, or more general guidance. In this report, reference is made as appropriate to specific regulations and codes in relevant areas.

10 The 1974 Act introduced general duties on employers and other duty holders to protect health and safety 'so far as is reasonably practicable' (SFAIRP). Risks should therefore be reduced to a level that is 'as low as is reasonably practicable' (ALARP). Where it is judged that reliance on the general duties is insufficient, more specific controls are introduced through regulations. For some more severe hazards, including some discussed in subsequent chapters of this report, an authorisation or 'permissioning' system has been introduced. This may take a number of different forms such as, in the case for nuclear installations (eg power stations), a licensing regime under which the regulator sets licence conditions which the licensee must meet, or, as is the case for major hazard sites such as chemical works, an authorisation scheme based on submission to and acceptance by HSE of a 'safety report' or 'safety case'.

11 There are some sets of regulations that are of particular significance in controlling the type of risks associated with the energy developments described in this report, such as the Control of Major Accident Hazards Regulations 1999 (COMAH). Reference to these regulations is made in the specific chapters dealing with specific developments.

12 An important feature of health and safety at work law is that it is both comprehensive and flexible. 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 mentioned later in this report) is immediately subject to legal requirements on those working with the new technology to achieve acceptable standards of safety. Specific new regulatory controls are not needed, though these may follow (for example, to impose a 'permissioning' regime) if the risks are sufficient to merit such action.

Achieving sensible risk management

13 A fundamental approach in health and safety at work law is to undertake an assessment of risks, using a methodical risk assessment process, and then to introduce appropriate controls, to the extent that is reasonably practicable. The meaning of the term 'so far as is reasonably practicable' has been refined in case law. It is a demanding standard. It is a requirement to take all measures to reduce risks until the sacrifice (time, trouble, effort and expense) of any further measures would be grossly disproportionate to the further risk reduction. The concept recognises that in an advanced, industrial society it is not possible to reduce risks to zero, nor would it be possible to require people to introduce every safety improvement that is physically possible regardless of the balance between the safety improvement achieved and the cost, except by virtually closing down British industry. Controls should be based around a hierarchy of actions, starting with the elimination of the risk and, if elimination is not reasonably practicable, action to protect against and/or mitigate it

(useful summaries of sensible control measures are published in *Successful health and safety management* and in *Managing health and safety: five steps to success*).

14 Breaches of the requirements of the HSW Act (and its associated regulations) by duty holders (usually employers, but duties are also placed on others including the self-employed, employees, suppliers and designers of work equipment) are breaches of criminal law and attract criminal sanctions. In the case of death resulting from a work activity, the possibility that manslaughter might be involved is always considered. The police are responsible for deciding whether to pursue a manslaughter investigation and whether to refer a case to the Crown Prosecution Service (in England and Wales) or the Procurator Fiscal (in Scotland) to consider possible manslaughter charges.

15 The objective of the Commission and Executive is to ensure that risks to the health and safety of workers and the public arising from work activities are properly controlled. The policy followed by the Commission and Executive is that they seek control regimes that are proportionate to the risk, thus achieving sensible risk management. This is reflected in what we expect duty holders to do to control risks and also in the use of HSE's own resources, concentrating action on areas where these resources will do most good. It is important to recognise that there are two elements to risk, the **likelihood** and the **consequences** or impact. Energy generation and related activities are predominantly characterised by low likelihood/high consequence risk, which makes their continued close regulation an imperative. It is the inherent nature of these processes, the hazard, that dominates here and hence the phrase 'major hazards' is often used to describe these activities.

16 HSE follows certain principles to ensure that the process of decision-making, including risk assessment and risk management, is acceptable (a useful summary of HSE's overall approach to risk management can be found in the publication *Reducing risks, protecting people*). The principles established include:

- HSE seeks to involve its stakeholders (as appropriate) in the decision-making process, with the aim of achieving robust and well-informed policy and interventions.
- HSE's approach aims to be as open and transparent as practicable.
- Both individual risk and societal concerns engendered by the activity are taken into account by HSE when deciding whether a risk is acceptable. 'Individual risk' relates to the potential, tangible harm to individuals. 'Societal concerns' (see paragraphs 18 to 20) arise with those hazards that have the potential to impact seriously on society and which, if realised, could provoke a socio-political response. 'Societal risk', that is the risk of an incident which could cause multiple casualties, can be a contributor to such societal concerns.
- In addressing risks, HSE sees relevant **good practice** as a minimum requirement. Established good practice is an important concept for both duty holders and regulators because, if properly formulated, it represents a consensus between stakeholders on an adequate response to a risk. Good practice should evolve to reflect changes in technological feasibility and regulatory expectations.
- HSE expects duty holders to recognise and act on the greater potential for reducing risks by considering safety at the design stage, thus reducing risks

throughout the lifecycle of a hazard by designing in health and safety from the start.

- HSE adopts a **precautionary approach** in addressing **uncertainty** (arising from incomplete knowledge about the hazard and/or how it causes harm) by erring on the side of safety. This approach is reflected by, for example, giving more weight to the consequences of a risk than its likelihood where a risk assessment is subject to a high degree of uncertainty, or, when considering the trade-off between the costs of control measures against the benefits from the reduction in harm they achieve, applying a premium to the benefits side. However, this does not mean stopping activities simply because there is uncertainty about the risk likelihood. HSE also promotes action aimed at narrowing uncertainty through focussed research and review of knowledge.
- Where appropriate, the assessment of risk and the risk control systems adopted should take account of both uncertainty and foreseeability.
- An approach that achieves sensible risk management and action proportionate to risk, not the elimination of all risk, is expected.

17 These principles operate within the **tolerability of risk** framework (first set out in *The tolerability of risk from nuclear power stations*), which provides guiding criteria for HSE to inform its judgements about the level of risk when reaching a decision on regulatory control. The framework is constructed to reflect how people in general view risk. At one end of the spectrum, some risks are so high that they would usually (unless there are exceptional circumstances or highly specific concerns, such as those related to national security) be viewed as unacceptable, whatever the benefits that might be gained by taking the risk. At the other end, some risks are seen as too trivial to be of concern. In between are risks at levels at which they are of concern but can be tolerated provided that they are reduced ALARP.

Establishing and reflecting societal concerns

18 There has been much debate about the way in which societal concerns (defined earlier, see paragraph 16) are taken into account in decision making. To some extent it may be possible to do this in a quantitative or semi-quantitative manner, for example, estimating the costs and benefits associated with the ‘societal risk’ of multiple fatalities from accidents or from areas of land over which special agricultural controls need to be imposed following a release, and/or by the use of ‘aversion factors’. However, there are aspects of societal concerns that cannot easily be treated in this way. HSE believes it must take account of public values and expectations in the form of the commonly held views and opinions of society. Ignoring societal concerns would undermine public trust in the regulatory decision-making process and in the regulator. Decision making has to recognise the importance of expert judgement, but also ensure that this is properly and appropriately informed by societal values and expectations in determining what level of risk is tolerable or acceptable. In taking a view on tolerability, a number of decision criteria are used:

- equity-based criteria, which start with the premise that all individuals have unconditional rights to certain levels of protection;
- utility-based criteria, which look at the relative costs and benefits of control measures; and

- technology-based criteria, which look to the ‘state of the art’ to control risk.

19 Achieving the right balance between these criteria is not something to be left to the regulator in isolation – society’s values and expectations are critical to this decision making. Ultimately decisions on acceptable levels of risk are for society to take. In some cases the judgements will be made by the Government or Parliament. For example, HSE is currently working with Departments to present options to the Government on issues relating to societal risk and land use planning around major hazard installations.

20 We believe that we must be active in raising the quality of the public debate by promoting, informing and leading dialogues on risk. The Commission and Executive aim to provide information and improve the way we engage our stakeholders, so we can respond appropriately to societal concerns in a way which taps considered public preferences. We have become increasingly aware of the need to extend the scope of stakeholder consultation to capture the voices of not only special interest groups who have an abiding interest in occupational health and safety, but also the wider constituency of those affected, directly or indirectly, by work activities, including the wider public.

Conclusion

21 We have, in Great Britain, a mature and well-established system of control of the risks to workers and the public arising from work activities, underpinned by legislation and both international and domestic standards. This system is comprehensive and flexible enough to deal with new risks and hazards, achieving sensible risk management. It has allowed Britain to benefit from levels of public and worker safety which are comparable with the best in the world and achieve high levels of public confidence as measured by opinion surveys. In subsequent chapters we examine the application of this general approach to the new energy developments we are asked to assess.

2 NATURAL GAS STORAGE

22 This chapter covers control of risks associated with natural gas storage, including liquefied natural gas (LNG) imports, onshore salt-cavity storage and storage in strata (onshore and offshore).

The technology

23 As the UK becomes a net importer of natural gas, there is an increasing need for gas storage and associated infrastructure. There are already several proposals for both expanding current facilities and for building new ones. These include storage in salt cavities, in strata, both on and offshore (in depleted oil and gas fields) and LNG storage and import facilities.

Salt cavities

24 The use of underground cavities in salt rock formations to store natural gas is long established and common around the world. The cavities are excavated by leaching (dissolving) the salt (halite) with water. The key properties of halite that make it suitable for storing gas are its very low permeability (ie fluids and gases cannot flow through it) and its plasticity. Salt cavities are therefore gas tight and tend to be self-sealing around the well-bore casing.

25 Suitable salt beds occur in a number of locations in Britain. The longest established site was commissioned in 1979 at Hornsea in East Yorkshire. At the beginning of 2006 there were four operational salt cavity storage sites in Great Britain: Hornsea, East Yorkshire; Seal Sands, Teeside; Holford, Cheshire; and Hole House, Cheshire. New facilities are being developed or going through the land-use planning process in Cheshire, Lancashire and East Yorkshire.

26 In the UK, typical cavities will have a diameter of 50–100 m at depths of up to 1900 m. Each site may have a number of cavities connected by pipelines to a common import and export facility. Gas is injected into storage from the national transmission system (NTS), stored at pressures up to 300 barg (depending on cavern depth) and returned to the NTS when required. The storage capacity varies from site to site. For example, at Hornsea it is 0.28 billion cubic metres (bcm), the development at Aldborough is 0.42 bcm, and at Hole House it is 0.024 bcm. How long each storage facility can provide gas to the network depends on the capacity and maximum delivery rate, and is site specific.

27 Gas is stored in salt cavities offshore in the USA, although currently there are no facilities in the UK.

Storage in strata on and offshore (in depleted oil and gas fields)

28 The storage of natural gas in spent or nearly spent onshore and offshore oil or gas wells has become increasingly attractive to meet fluctuations in supply needs. The process is the reverse of the traditional extraction process. Gas, under pressure, is

returned to the underground porous rock formation that contained (or still contains) oil or gas or both trapped within it. In preparation for storage, additional wells are normally drilled or workovers on the existing wells carried out or both. Gas is injected into the reservoir via pipelines from the NTS, stored, and returned to the NTS when required. The technology is established pipeline and well practice.

29 Onshore, a site has been operating at Hatfield Moor near Doncaster since 2001. Further sites in Hampshire, Lincolnshire and the east coast are currently in development or going through the land-use planning process. Storage capacity and duration varies from site to site.

30 Currently there is only one UK facility offshore and HSE is not aware of any other proposals in the UK. The Rough field, located in the southern North Sea, has a total storage capacity of 2.8 bcm and stores gas at pressures over 200 barg. It is currently the largest gas storage facility in the UK (it accounts for 80% of UK storage capacity) and is able to meet approximately 10% of current national peak day demand. At maximum deliverability, the storage could last for approximately 80 days.

31 The facility consists of a partially depleted gas field, originally developed in 1975 to produce natural gas and converted to a gas storage facility in 1985. Gas is injected into the reservoir from the NTS at Easington at times of low demand and withdrawn from storage and fed back into the NTS in periods of high demand.

Liquefied natural gas (LNG) storage and import facilities

32 Natural gas can be liquefied by cooling it to minus 161 °C. In this form it is known as liquefied natural gas or LNG. LNG occupies 1/600th of the volume of gas at normal temperature and pressure, which makes it easier to store and transport in large quantities.

33 Large onshore LNG storage facilities have operated in the UK for over 40 years and are common throughout the world. LNG was also imported by ship into the UK at Canvey Island from the mid-1960s until the late 1980s, the facility being closed in 1994. Today LNG is used in the UK for 'peak shave' requirements (meeting short-duration high-level demand) and imported by ship to meet gas demand throughout the year.

34 At the beginning of 2005 there were five strategic LNG storage sites in the UK. These were built approximately 30 years ago as 'peak shave' plants to reinforce gas supplies at vulnerable parts of the NTS. During the summer, when demand for gas is low, the sites take gas from the NTS, liquefy it, and store it at atmospheric pressure. They export the gas back to the NTS to meet peak day demand in the winter, typically for five days per year. There are also four smaller LNG storage sites, in Scotland, which are supplied with LNG by road tanker and provide gas for remote networks isolated from the NTS.

35 The Isle of Grain facility is an import terminal and receives gas from seagoing LNG tankers to supply the NTS throughout the year. Two LNG import facilities are being developed in Milford Haven and there are proposals to import and store LNG at Canvey Island.

36 HSE is aware that companies have considered building LNG import facilities offshore and transporting the gas by pipeline to an onshore reception terminal. This may include offloading gas directly from the LNG ship into the pipeline. There are also proposals in the UK to bring LNG by ship into port, regasify it on board ship, and then offload it directly into the NTS.

Health and safety risks

37 The predominant hazard on these facilities is from the natural gas, either as a gas or liquid, although other hazardous substances such as methanol or liquefied petroleum gas (LPG) may be present.

38 Natural gas is not toxic but can act as an asphyxiant by displacing oxygen in air. It is extremely flammable at concentrations of about 5–15%. The potential hazards are associated with fires and explosions, for example flame contact, thermal radiation and explosion overpressures. The consequences of such an incident depend on the extent of the fire or overpressure. A number of types of fire and explosion can occur including a jet flame, fireball, flash fire, vapour cloud explosion and pool fires. HSE and industry use a suite of risk assessment models to determine the extent, severity and likelihood of these release scenarios. HSE also uses these assessments when advising local authorities in land-use planning.

39 A major incident at an onshore facility has the potential to harm large numbers of people working on the facility and people off site. The potential consequences of a serious incident on an offshore facility were shown in the Piper Alpha disaster in 1988 when 167 people were killed. For this reason, these facilities are commonly referred to as major hazard installations and stringent safety standards are required to minimise the risk. These include both engineering standards and management systems.

40 The risks from these facilities are controlled by a hierarchy of measures involving:

- inherent safety;
- prevention;
- control;
- mitigation;
- for onshore facilities, consideration of safety in land-use planning applications aimed at minimising the risks to people working and living around the site. These apply to new establishments and to development around the facility.

41 How these controls are achieved is described later in this report.

42 A separate area of risk is the possible consequences of loss of pressure or supply leading to a gas supply emergency. Under the Gas Safety (Management) Regulations 1996 (GSMR), operators of natural gas pipelines are required to minimise the risk of a gas supply emergency. This requires them to ensure that the pressure and gas composition in the network is maintained within certain limits so that when gas is

delivered to consumers it is at a pressure sufficient for the gas appliances work safely. Loss of pressure or supply can cause appliances or pilot lights to go out and, if safety devices fail to work or are not fitted, there is a risk of unignited gas entering premises which subsequently ignites. Overpressure can lead to excessive flame height or flame lift-off, and carbon monoxide can be produced if pressure is not maintained within range. Some 19 million domestic consumers could be affected.

43 Gas storage sites and LNG import terminals play an important role in maintaining safe network pressure. Where the demand for gas cannot be met from the UK's gas production facilities or from pipelines connecting the UK and Europe (UK–Belgium interconnector, UK–Norway Vesterled pipeline) both LNG imports and gas from storage provide additional supplies. The arrangements for ensuring safe pressure are set out in an operator's GSMR safety case, which describes how these facilities contribute. The safety case has to be accepted by HSE before gas can be conveyed.

Regulatory strategy

44 Building on the overall approach described in chapter 1, a number of specific sets of regulations govern the safety of these facilities in relation to the risk of major accident. General occupational health and safety legislation governs the more routine health and safety risks that arise at these sites. The legislation aims to ensure that the risks are managed sensibly. The main legislation is:

- the Control of Major Accident Hazards Regulations 1999 (COMAH);
- the Borehole Sites and Operations Regulations 1995 (BSOR);
- the Offshore Installations (Safety Case) Regulations 2005 (OSCR), which have replaced the previous 1992 Regulations (subject to certain transitional arrangements), underpinned by associated offshore regulations;
- the Pipelines Safety Regulations 1996 (PSR).

45 HSE also acts as a statutory consultee in advising planning authorities about the safety of these sites. The main requirements of the legislation and how they apply to each of the facilities are discussed below (paragraphs 64 to 67).

46 HSE starts from the position that operators must comply with the extensive range of design and operational standards that apply to these types of import and storage facilities. Where different standards are proposed, an equivalent level of safety should be achieved. Furthermore, operators have to show that it is not reasonably practicable to do more to reduce the risks, for example, higher standards may be required depending on the location of the facility and number of people that could be harmed by an incident on and off site.

Control of Major Accident Hazards Regulations 1999 (COMAH)

47 COMAH applies to onshore LNG storage and import facilities and salt cavity storage when 50 tonnes or more natural gas is stored or present on the establishment. COMAH introduces a variety of controls on major accident hazard sites, referring to the need to take 'all measures necessary' (AMN), which is taken to refer to measures that are reasonably practicable. Where the quantity of gas is 200 tonnes or more, operators are required to prepare a safety report. COMAH aims to prevent major

accidents involving dangerous substances and to limit the consequences of any accident to people and the environment.

48 In England and Wales a competent authority (CA), comprising HSE and the Environment Agency (EA), enforces the COMAH Regulations. In Scotland, HSE and the Scottish Environment Protection Agency (SEPA) are the CA. The CA assesses the safety report in accordance with requirements of its COMAH safety report assessment manual. In the case of gas storage and import establishments, HSE is the lead authority.

49 An operator who plans to build a new gas storage establishment has to submit information to the CA in a pre-construction safety report (PCSR) before construction starts. Another similar report must be sent to the CA before dangerous substances are introduced into the plant – the pre-operational safety report (POSR). The operator has to ensure that the construction and operation of an establishment does not start until they have received the conclusions of the CA's examination of the relevant report. This does not prevent early preparatory work, such as levelling or extending services to the site. However, any work to do with the positioning of processes, storage, pipelines, control rooms or offices, which may have a significant impact on safety and would be costly and time-consuming to reverse, must not be started before the competent authority has communicated the conclusions of its examination of the PCSR.

50 The purpose of the PCSR is to ensure that safety is fully considered at the design stage. If things need to be improved or altered, then it is easier to make those changes at the design stage rather than later on. When the CA assesses a safety report it is looking for a demonstration that adequate safety and reliability have been incorporated into the design, the application of good practice and for concepts which reduce the risks such that they are ALARP.

51 The POSR must demonstrate that the operator has taken all measures necessary to prevent major accidents and to limit the consequences to people and the environment of any that do occur. If the CA considers that there is evidence of serious deficiency in any of the measures taken or proposed, it will prohibit the operation of those parts of any establishment which are seriously deficient.

52 As well as assessing the safety reports, the CA is required to organise an adequate system of inspections while the establishment is operational – this is developed towards the end of the POSR assessment. The CA will also investigate incidents and accidents which occur on site.

53 Regular inspection visits will be made during the construction phase to ensure that the integrity of the plant and equipment is in accordance with the information provided in the PCSR, including adherence to recognised and accepted standards and good practice. The construction activities on site will also be inspected to check that the operator is doing all that is necessary to ensure the health and safety of those at work.

54 Under COMAH, operators of gas storage establishments are also required to produce an on-site emergency plan before the establishment starts to operate and must

provide information to the local authority to assist them in their production of an off-site emergency plan. The plan's objectives are to contain and control incidents to minimise the effects and to limit damage to people, the environment and property.

Borehole Sites and Operations Regulations 1995 (BSOR)

55 A place onshore at which an activity or operation is to be undertaken in connection with the extraction of minerals by a borehole is defined as a 'borehole site' and BSOR applies. Boreholes connecting surface facilities to underground gas storage, such as at salt cavities and strata storage sites, are therefore covered by BSOR. Their principal aim is to ensure the integrity of the borehole. They apply from the beginning of operations on the site and through the life of the establishment until the borehole is abandoned.

56 BSOR require operators to notify HSE in advance of well operations starting or significant changes to existing operations. A health and safety document has to be prepared demonstrating that the risks have been assessed and adequate measures concerning the design, use and maintenance of the borehole site and of its plant will be taken. The plan should address fire and explosion risks and in particular measures to prevent blowouts and uncontrolled escape of flammable gases and for detecting leaks. A fire protection plan is required and on-site emergency arrangements established.

Offshore Installations (Safety Case) Regulations 2005 (OSCR) and associated legislation

57 These Regulations apply to all offshore oil and gas installations including those used for the offshore storage of gas and the recovery of stored gas.

58 OSCR requires all offshore installations to be operated in UK waters to have a safety case accepted in writing by HSE before they start operating. The cases are assessed in accordance with HSE's Offshore Safety Division's safety case assessment manual. Those parts of an installation that are identified as critical for the safety of the installation must be verified as suitable by independent and competent people. A safety case requires operators/owners to describe management systems and show a systematic and structured approach to managing the major hazards on the installation. A safety case is the means by which a duty holder shows that:

- all hazards that could cause a major accident have been identified and evaluated;
- controls are in place to reduce the risks to the lowest level that is reasonably practicable;
- the management system is adequate to ensure compliance with all health and safety law.

59 OSCR is supported by more specific regulations setting standards for:

- management;
- fire and explosion protection and emergency response; and
- the structural integrity of installations and wells.

Pipelines Safety Regulations 1996(PSR)

60 The safety of pipelines that convey gas from the facilities onshore and offshore into the NTS is governed by PSR. Pipelines include compressor, pressure reduction and block valve installations. They require pipeline operators to design, build and operate pipelines to ensure that they are safe SFAIRP. Operators of major accident hazard pipelines, such as gas transmission pipelines operating at pressures above 7 barg and LNG pipelines, are required to notify HSE before construction, use and significant modification, providing details of the design of the pipeline and operating conditions. They are also required to prepare a Major Accident Prevention Document (MAPD) demonstrating that potential major accident hazards have been identified and that there is a safety management system adequate to minimise the risks.

61 HSE assesses the pipeline notifications, carries out inspections during construction and operation and investigates incidents.

62 Under PSR, the operator of an onshore pipeline is required to have an emergency plan for dealing with an actual or potential major incident. Each local authority through which the pipelines passes is also required to prepare an adequate plan detailing how an emergency on the pipeline will be dealt with.

63 PSR does not apply to pipelines contained wholly within the premises of an establishment. However, the safety of such a pipeline would have to be considered as part of the COMAH site safety report.

Land-use planning and hazardous substances consent

64 The aim of health and safety advice relating to land-use planning is to mitigate the effects of a major accident on the population in the vicinity of hazardous installations. All onshore establishments where the presence of certain hazardous substances is (or will be) above a specified threshold quantity must apply to the Hazardous Substances Authority (HSA) – usually the local planning authority – for consent under the Planning (Hazardous Substances) Regulations 1992 (PHSR). PHSR applies at salt cavities, strata storage sites and LNG facilities when 15 tonnes or more of natural gas is present. HSE is one of several organisations that the HSA must consult as to the advisability or otherwise of locating a major hazard establishment in the location designated. HSE's role as a consultee is to advise the HSA on safety matters. In addition to applying for consent, a separate planning application must also be made to the local planning authority to carry out the development.

65 HSE assesses the risks based on the consent particulars (such as pressure, temperature and nature and size of the storage vessels) and, in some cases, other plant features which significantly affect the risk to people and which may need to become conditions of consent. HSE advises on health and safety issues within its expertise and which are covered by the HSW Act. Any issues about the scope of planning legislation are a matter for the planning authority.

66 If consent is granted, HSE will set a consultation zone around the major hazard site and notify the planning authority. Subsequently, whenever certain developments are proposed within the consultation zone (typically those that increase the number or vulnerability of people), HSE is consulted as to the advisability or otherwise of locating the particular development there. However, the decision to grant planning permission rests with the planning authority.

67 Local planning authorities also consult HSE for land-use planning advice for developments around major accident hazard pipelines.

Standards

68 Safety standards developed in the onshore and offshore chemical and oil and gas industries apply at these facilities. They cover both technical standards and management systems. They have developed through close co-operation between industry representatives, regulatory authorities and other key stakeholders, in the UK, Europe and internationally. They are regularly reviewed by standards-making bodies such as the British Standards Institution (BSI), International Organisation for Standardisation (ISO), European CEN standards committees and organisations such as the American Petroleum Institution (API) and American Society of Mechanical Engineers (ASME). There are also a number of UK industry bodies actively contributing to the development of safety standards. These include the United Kingdom Offshore Operator's Association (UKOOA), United Kingdom Onshore Pipeline Operator's Association (UKOPA), and Institution of Gas Engineers and Managers (IGEM) and HSE works closely with these organisations.

69 Specific standards applying to each of these facilities are discussed below.

Salt cavities

70 The main areas of concern at a salt cavity are the import and export gas pipeline, salt cavity, well head and on-site process plant.

71 HSE expects that European Standard BS EN 1918: 1998, in particular Part 3 (*Functional recommendations for storage in solution-mined salt cavities*) and Part 5 (*Functional recommendations for surface facilities*), will be adopted. The design of the well casing, well head valve arrangements and subsurface safety valve systems are well established, covering, for example, the requirements for emergency fail-safe closure to stop the gas flowing from the cavern if the well-head valves are damaged or inoperable. There are detailed standards covering surface plant such as compressors, pipework, and emergency shutdown systems.

72 A detailed geological assessment is required to demonstrate the integrity of the cavities. They must be sufficiently deep for the overlying rock to contain the gas pressure when fully charged and have adequate thickness and purity of salt above the cavern to ensure a gas-tight seal. The overlying rock formations should be of appropriate type, strength and thickness to contain the gas pressure and prevent subsidence. There should be sufficient separation between cavities or other mines and boreholes to ensure that there is no pressure communication between them. Internal

explosions in cavities are highly improbable since the internal gas pressure will prevent the ingress of air to form an explosive mixture.

73 The cavity's access borehole should be designed and constructed to the same standards as oil and gas wells. The steel casings should conform to API standards for oilfield tubulars; they should be fully cemented in place. A series of valves should be fitted to the well at the surface. The valve assembly should also comply with API standards, should allow for double isolation of the stored gas, be capable of being remotely operated and close automatically if the control system fails. The recoverable tubing assembly through which the gas actually passes should also conform to API standards; it should include isolation packers and seal assemblies to seal it in place at both ends of the borehole; it should include a fail-closed subsurface safety valve as back-up to the well-head valve assembly.

Liquefied natural gas (LNG) storage and import facilities

74 The main areas of concern at these facilities are the safety of the LNG ship, the tanker loading/unloading line, storage tanks, process plant and pipework, and the export pipeline.

75 LNG storage and import terminals have to meet recognised safety standards such as British Standard BS EN 1473: 1997 *Installation and equipment for liquefied natural gas. Design of onshore installations*, which covers the design requirements for the range of plant and equipment. There are more detailed standards covering specific plant, which include the design of the storage tanks (BS 7777: 1993 *Flat-bottomed, vertical, cylindrical storage tanks for low temperature service*), vaporisers, process plant, electrical equipment and emergency shutdown systems.

76 Two areas of particular interest are the design of the storage tanks and the ship to shore systems. The design of LNG storage tanks has developed over many years resulting in operators of new facilities in the UK adopting full containment storage tanks, an improvement on earlier single and double containment designs. Nickel steel is now used for the inner tank to prevent *zip failures*. British Standard BS EN 1532: 1997 *Installation and equipment for liquefied natural gas Ship to Shore interface* covers the standards required for the design of the jetty and pipeline taking LNG from the ship to the storage tanks. ASME *Code for pressure piping – B31, Chemical plant and petroleum refinery piping* B31.3 addresses design requirements for the cryogenic LNG pipeline.

77 These facilities, including the unloading equipment at the jetty, are covered by COMAH. LNG on the ship at the jetty is not considered to be part of the inventory of the COMAH establishment, but must be taken into account if it could cause or exacerbate a major incident. HSE advises local authorities about the safety risks through the land-use planning system. It also identifies the interfaces between HSE and other regulatory bodies who also have responsibilities associated with LNG terminals.

78 Harbours used for unloading LNG are managed by statutory harbour authorities, which have duties under the Dangerous Substances in Harbour Areas Regulations 1987. Harbour authorities control the marine traffic into and through the

harbour, and the berthing and moving of ships. They are bound by the Port Marine Safety Code, compliance with which is monitored by the Maritime and Coastguard Agency (MCA) and the Department for Transport. Maritime safety is dealt with under maritime safety legislation but the functions, responsibilities and means of co-operation between HSE and MCA are set out in a Memorandum of Understanding.

79 HSE continues to review LNG incidents worldwide to ensure lessons learned are implemented in the UK.

Onshore strata storage

80 The main hazards concern the integrity of the well casing and hazards associated with a well-head failure, surface pipework and plant. BS EN 1918-2: 1998 *Gas supply systems. Underground Gas Storage. Functional recommendations for storage in oil and gas fields* is relevant to safety of these sites. Preventative measures include automatic down-hole and surface safety valves, which isolate the well in an emergency. Incidents involving the release of dangerous substances in normal operations are rare. The integrity of the storage reservoir, having formed naturally, is of low concern, as it is not pressurised above its historical pressure so as not to compromise the reservoir cap.

81 COMAH (by virtue of regulation 3(3)(c)) does not include storage in natural strata, but COMAH will apply to the surface plant if the quantity of gas present meets the COMAH thresholds. Typically, the amount of gas in the above-ground plant will be around 50 tonnes, attracting the general provisions in COMAH but not the specific requirements in regulations 7–14 (such as preparation of a safety report and off-site emergency plan).

82 HSE's intervention for new sites is triggered by the borehole notification under BSOR. HSE wells engineering specialists review the health and safety document to ensure the hazards are being managed properly. Fire and explosion risks and on-site emergency arrangements are looked at. Off-site emergency plans are required for the import and export pipelines under PSR.

Offshore strata storage

83 The significant hazards are those associated with offshore gas production. These hazards are well understood, as are the measures required to minimise the risk to offshore workers. Prevention of loss of containment of gas is paramount and the safety case for the installation will address integrity of the import and export pipelines and that of the plant and equipment on the installation platform.

Pipelines associated with gas storage sites

84 There are a number of authoritative pipeline standards governing the safety of both onshore and offshore high-pressure natural gas and LNG pipelines. The standards cover all aspects related to ensuring engineering integrity and in the case of onshore pipelines, routing considerations to ensure that the risks to surrounding populations is minimised.

Conclusion

85 Overall, the hazards and risks of the onshore aspects of LNG import and storage facilities and of storage of natural gas in salt cavities and in strata, onshore and offshore, are well understood.

86 Effective safety standards, including technical standards and management systems, have developed to ensure that the risks from future developments can be managed sensibly. The standards have developed internationally over many years and are regularly reviewed and revised to address changes in technology and incorporate improvements. HSE monitors incidents worldwide to ensure that lessons are learned and, where necessary, improvements made in the UK.

87 HSE's regulatory strategy for ensuring the risks are properly controlled is robust. There are no significant gaps in legislation, although a number of areas are under review (summarised in paragraphs 89 to 95 below). HSE, as the principal safety regulatory body, has 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.

88 There are, however, a number of issues described below, which are under review.

89 The COMAH Regulations do not apply to storage in onshore strata. This could appear anomalous, as salt cavity storage is covered by the COMAH Regulations. In addition, some European Community countries are interpreting the Seveso Directives (Seveso I and II) as applying to strata storage, which implies that the COMAH Regulations (which implement the Directive) should be applied to such storage. With this technique of gas storage liable to be developed at further sites in future, it would be sensible to seek consistency of interpretation within Europe of the Seveso Directives. A consistent approach will be sought, and amendment of COMAH considered.

90 HSC has considered amendments to PSR, which would require mandatory testing of off-site pipeline emergency plans. The current requirements are inconsistent with other major hazard legislation and will be reviewed.

91 LNG import facilities are not currently specifically referred to in GSMR. However, they could play an important role in minimising the risk of a gas supply emergency. Therefore, to ensure that the duty of operators of these facilities to co-operate with the NTS operator is clear, HSE will consider proposing an amendment to GSMR to include LNG import facilities.

92 A new 'Application Outside Great Britain Order' (AOGBO) may be needed to apply the HSW Act to the possible development of offshore LNG terminals.

93 HSE will continue to work with DTI to review gas quality arrangements.

94 Safety of LNG ships (both ships that offload gas into onshore storage vessels and those that offload directly into a pipeline at on shore jetty) is dealt with under

maritime legislation and not health and safety at work legislation. HSE is currently discussing proposals with an operator about importing LNG into the UK directly from an LNG ship, regasifying it onboard ship and offloading it directly into a pipeline. HSE has adequate enforcement powers to deal with risks that arise once gas is offloaded into the pipeline.

95 Finally, HSE is continuing to review its approach to the ‘societal concern’ (see chapter 1, paragraphs 18 to 20) aspects of new gas storage developments, as part of its continuing review of risks from existing and proposed major hazard installations. These aspects will be kept under review.

3 CARBON CAPTURE AND STORAGE

The technology

96 Governments around the world are considering the potential of carbon dioxide capture and storage (CCS) as a way of slowing the rate of increase of carbon dioxide (CO₂) in the atmosphere by reducing the amount of carbon dioxide that is released into the air. It is hoped that CCS, together with improved energy efficiency measures and greater use of renewable energy sources, could make a significant contribution to stabilising the atmospheric CO₂ concentration at a tolerable level, providing time for lower carbon technologies to be developed and come into widespread use.

97 CCS is the name given to a series of processes by which carbon dioxide is separated from the gases produced by large power stations or industrial plants, purified, compressed and transported to locations where it can be stored securely for a very long time, probably indefinitely. For most UK projects, underground storage, probably below the seabed, is likely to be the most viable and environmentally acceptable of the several options available.

98 The technologies involved in the three stages of CCS (ie CO₂ capture, transport and storage) are summarised in paragraphs 99 to 113.

Carbon dioxide capture

99 Carbon capture is best applied to large stationary sources such as fossil-fuelled power stations and major industrial plants where the CO₂ in their gaseous effluent streams can be separated at a suitable stage in the process. Once removed, the captured carbon dioxide can be moved to a long-term storage location. The technologies can be divided into those in which the capture takes place after the fossil fuel has been burned (post-combustion carbon capture) and those where the carbon is removed before burning takes place (pre-combustion capture).

100 Post-combustion carbon capture involves either traditional combustion (ie normal combustion of the fossil fuel in air) or oxyfuel combustion. Traditional combustion gases contain a lot of nitrogen from the air in which the fuel was burned, so the concentration of CO₂ in the flue gases is quite low, typically 4–14%. This makes the capture process more costly and increases energy consumption.

101 Oxyfuel combustion uses a blend of almost pure oxygen diluted with carbon dioxide recycled from the process. The absence of nitrogen makes the concentration of CO₂ available for capture much higher than from traditional combustion. Both traditional and oxyfuel combustion produce a large amount of water vapour that must be removed before carbon dioxide capture can take place.

102 Pre-combustion carbon capture involves gasification and steam reforming to remove carbon from fossil fuels before combustion. These techniques produce a carbon-free fuel and a relatively pure carbon dioxide stream and substantially less water vapour.

103 Gasification has been used for almost a century. Only a small amount of the solid fuel, usually coal, coke, biomass, waste etc is allowed to burn normally. The majority of the fuel is chemically broken down to produce a mixture of hydrogen, carbon monoxide and other gaseous products called 'syngas'. This is further processed to pure hydrogen and a concentrated CO₂ stream suitable for capture.

104 In integrated gasification combined cycle (IGCC), the 'syngas' is used to power combustion and steam turbines for electricity generation. Steam reforming of natural gas is the major source of hydrogen in the world today. The process involves reacting natural gas with steam at high temperature. It produces high quality hydrogen and a concentrated stream of carbon dioxide suitable for capture.

Separation technologies

105 There is a range of technologies available for separating carbon dioxide from the gaseous effluent streams of power stations and industrial plants, and these are at different stages of development. Some, such as post-combustion amine scrubbing (chemical absorption), have been used for over 60 years for removing hydrogen sulphide and carbon dioxide from hydrocarbon gas streams; others are still at an early stage in their development.

Transport of carbon dioxide

106 Once captured, the purified carbon dioxide needs to be transported, usually by pipeline, to a storage location, which is likely to be some considerable distance away. The enormous amount of CO₂ that CCS schemes would involve makes transport as a gas impractical. By using high pressures, typically between 75 and 200 bars, carbon dioxide can be converted from a gas into what is known as a supercritical fluid or the 'dense phase'. In this form it has a similar density to water and can be pumped like a liquid, albeit one with extremely low viscosity.

107 In the future, it may be necessary to move CO₂ by very large ocean-going tankers. While this has not yet been formally demonstrated, designs for these have been produced and there is much relevant experience to draw on from the transport of LPG and LNG.

Storage of carbon dioxide

108 There are several potential options for storing captured CO₂, but the use of suitable natural geological formations is currently considered the most viable and environmentally acceptable. The geologic formations considered suitable for CO₂ storage are layers of porous rock deep underground that are 'capped' by a layer of non-porous rock above them. A well would be drilled down into the porous rock and pressurized CO₂ injected into it. CO₂ flows upward until it encounters the layer of non-porous rock and becomes trapped.

109 There are three main types of geologic formations into which CO₂ could be injected and stored. Each presents different opportunities and challenges:

Depleted oil and gas reservoirs

110 These formations have held crude oil and natural gas over geologic time frames. In general, they comprise a bed of porous rock covered with a dome shaped layer of non-porous rock. Injecting CO₂ into a depleted oil reservoir has been used by the oil industry, particularly in North America, for several decades to enhance oil recovery (EOR). The CO₂ lowers the viscosity of the oil enabling it to slip through the pores in the rock and flow toward a recovery well. Much of the operational experience gained from EOR will be valuable and transferable to carbon dioxide storage projects. Similarly, a wide range of tried and tested equipment is commercially available. There are, however, some significant differences between these technologies. The pressures used in EOR are usually lower than those proposed for the next generation of CCS projects, and EOR usually has the goal of minimising the amount of CO₂ left in the ground, whereas CCS has the opposite objective.

Unmineable coal seams

111 These coal seams are either too deep underground or too thin to be mined economically. All coals have varying amounts of natural gas (methane) adsorbed onto their surfaces. Wells can be drilled into unmineable coal beds to recover this coal bed methane (see chapter 7). The amount of methane recovered from coal beds can be significantly increased by injecting CO₂, which preferentially adsorbs onto the surface of the coal, displacing methane. Consequently, in a similar manner to EOR, injecting CO₂ into coal seams could provide increased fossil fuel recovery as well as an opportunity for CO₂ storage.

Saline aquifers

112 These are layers of porous rock saturated with brine. They are much more commonplace than coal seams or oil- and gas-bearing rock and so have enormous potential for CO₂ storage. Saline formations frequently contain minerals that react with injected CO₂, forming solid carbonates. These reactions can increase the permanence of storage but they may also plug up the formation around the injection well. Research is ongoing to determine how to maximise the advantages of these mineralisation reactions.

113 Generally, less is known about the suitability of saline formations for CO₂ storage compared to crude oil reservoirs. In the Sleipner West field, off the coast of Norway, a million tonnes of CO₂ a year are separated from natural gas at the well head, injected and stored below the seabed in the Utsira sandstone aquifer. This project is steadily adding to the knowledge base on the operational issues associated with aquifer storage.

Industrial experience with carbon dioxide

114 Carbon dioxide has been used or produced by industry for a very long time; it is a fundamental aspect of most brewing and baking processes. It has been a

merchanted commodity for almost a century, moved from producer to customer in gaseous, liquid or solid form and used in refrigeration, carbonation of drinks, fire extinguishing systems, welding etc.

115 Like most substances, carbon dioxide can exist as a gas, a liquid or a solid. Which of these states it actually occupies depends upon its temperature and the pressure to which it is subjected. In addition to these normally encountered physical states, carbon dioxide can also exist in an unusual one described as a supercritical fluid or the 'dense phase'. When present in this form, CO₂ has some of the properties of a gas and some of those of a liquid. For this state to exist, the pressure must be greater than 73 bar and the temperature above 31 °C. If either the temperature or pressure falls below these critical values, the dense phase will change to liquid, gaseous or solid carbon dioxide.

116 The use of supercritical carbon dioxide (scCO₂) by process industries has increased rapidly over the last five years. Combining the low viscosity expected from a gas with the density and very high solubilising power of a liquid solvent, process engineers have been quick to exploit the opportunities presented by this unusual material.

117 Supercritical carbon dioxide is an extremely effective solvent. Production-scale processes using scCO₂ for the removal of caffeine from coffee and the extraction and recovery of many natural products, flavours and fragrances are all in routine operation. Similarly, the use of scCO₂ enables many chemical reactions to proceed more quickly or produce fewer by-products than would traditional process conditions. Several UK speciality chemical manufacturers are now using scCO₂ technology to synthesise high-value products.

118 While the use of scCO₂ by the process industry is providing a growing body of knowledge that will be useful for carbon capture projects, the huge difference in scale must be recognised. The extraction processes mentioned earlier typically have scCO₂ inventories of a few tonnes. The first generation of CCS projects could involve the transport and injection of several thousand tonnes of scCO₂ per day.

119 The movement of scCO₂ by pipeline at pressures in the range 75–175 bar is a very specialised but well-established technology. Within North America there are over 3000 km of pipeline dedicated to the transport of 45 million tonnes of dense phase carbon dioxide annually. The equipment necessary to compress, pump and control the long-distance transport of CO₂ at these pressures is well developed and commercially available. The pipelines used are typically made from low carbon steel and it is recognised that their integrity is heavily dependent on ensuring that the carbon dioxide has a very low moisture content and is free from other critical contaminants.

120 Wells have been drilled all around the world for natural gas containing high concentrations of CO₂. Some of these wells have suffered blowouts, well control problems and corrosion-related issues. These installations have provided a significant body of 'real world' operating experience that will provide useful background knowledge for future CCS projects.

121 There is significant international experience in the injection of supercritical carbon dioxide. Although the majority of this expertise is associated with enhanced oil recovery, geological storage of CO₂ has been ongoing for some time in three industrial scale projects – Sleipner in Norway and Salah in Algeria, and Weyburn in Canada. Each of these is putting more than one million tons of carbon dioxide into storage each year. The pressures used to date have generally been in the range 75–200 bar. It is possible that the next generation of CCS projects will need to use significantly higher injection pressures than these.

Health and safety risks

Health hazards

Carbon capture solvents

122 A range of organic amines, methanol, propylene carbonate and methyl-2-pyrrolidone are commonly used in CO₂ capture processes. These substances are well known and their properties have been fully categorised. All these chemicals are classified as hazardous substances and will present a risk to health from occupational exposure. Their lead health effect of concern is irritation to the eyes, skin and respiratory tract. Maximum exposure threshold concentrations and control standards have been established for all the chemicals currently used in carbon capture processes. These chemicals should be used in enclosed systems with exposure minimised through effective process design so that the risk from inhalation is well controlled. Respiratory protection will be required, however, for rare, unavoidable short-term activities that may result in high exposures, such as charging vessels and maintenance work. Similarly, it should be practicable to make skin contamination rare by ensuring contact is very infrequent through effective process design and training in the use of appropriate gloves and overalls when manual intervention is unavoidable.

Gaseous CO₂

123 At room temperature and pressure, carbon dioxide is a colourless, odourless gas that will not support combustion or human life. The gas has been recognised as a workplace hazard for over a century and its effects on people are well understood. Carbon dioxide is significantly heavier than air and many fatalities from asphyxiation have resulted from entry into pits, tanks, sumps or cellars where the gas has accumulated. It is particularly important that this hazard is recognised when assessing the risks associated with entry into confined spaces. It is also possible for dangerous levels of carbon dioxide to form out-of-doors, in trenches, depressions or valleys. This is particularly likely when the gas is colder than the surrounding air, which can occur following a high-pressure release.

124 When inhaled, CO₂ produces symptoms that depend upon its concentration and the length of exposure. These range from headaches and mild narcotic effects, through intoxication, to unconsciousness and finally asphyxiation. The concentrations at which the various levels of worker impairment occur have been studied and appropriate short- and long-term workplace exposure levels are recognised.

125 Even moderate concentrations of CO₂ may have detrimental effects on the cognitive and decision-making abilities of those exposed. Their impaired performance when carrying out safety-critical tasks represents a considerable hazard to the safety of individuals and the installation and must be recognised when considering workplace design and emergency response arrangements.

126 As with any gas under high pressure, compressed carbon dioxide contains a lot of stored energy. The release of this following even relatively minor failures in pressurised equipment can result in very serious consequences to neighbouring plant and personnel. A massive release of CO₂ would be a major accident.

Supercritical (dense phase) CO₂

127 Carbon dioxide can only exist in the liquid or supercritical/dense phase while under high pressure. Most current and future CCS projects use dense phase CO₂ where the pressure involved must be greater than 73 bar. Most of the hazards associated with dense phase CO₂ arise when this pressure suddenly falls or is lost completely. When present in the dense phase even a relatively small pressure drop can produce a large increase in the volume that the carbon dioxide occupies. This must be borne in mind during the design and operation of equipment handling dense phase CO₂.

128 A major pressure loss, eg a pipe rupture or valve failure, will lead to the volume occupied by the carbon dioxide increasing several hundred-fold as the dense phase 'boils' and becomes a gas. This rapid, violent expansion causes the temperature of the escaping CO₂ to fall very rapidly, frequently to below -80 °C. Particles of solid carbon dioxide (dry ice) will form in the escaping high velocity jet, frequently resulting in pea to marble-sized projectiles expelled at very high velocities. Cryogenic burns and impact injuries from the extremely cold jet of gas and entrained missiles are serious hazards to personnel.

129 Large quantities of dry ice may collect in the vicinity of release points and spread some distance over adjacent plant and equipment. As these deposits warm up, carbon dioxide gas will be produced as the solid dry ice changes directly into a gas. The localised high concentration of CO₂ that this produces represents a significant hazard to personnel. It is extremely important to ensure that the design and maintenance of gas monitoring and alarm systems are appropriate for the very low temperatures that may be present in the vicinity of CO₂ releases.

130 Beyond the area affected by the cooling and projectile hazard, a much larger area may have dangerously high levels of CO₂. The extent and concentration profile within this will depend on several factors including the type, amount and direction of the release, the local topography and the weather conditions. Those areas that are lower than the release point and particularly depressions, cellars and refuges are likely to see the highest concentrations.

Engineering hazards

131 In general, the technologies associated with the production and capture of carbon dioxide are mature and well understood. The associated hazards are recognised and effectively controlled by a well-developed framework of standards, codes of practice and guidance.

132 However, the scale of some future CCS projects may mean that engineers are working close to the edge of existing experience. The risks from extrapolation into unknown regions must be carefully managed, and the risks are significant. Dense phase CO₂ is highly invasive and the selection of appropriate materials for valve packing, seals and gaskets should be done with great care and from a position of knowledge not assumption. Dense phase CO₂ is capable of dissolving materials, for example, magnesium metal, that are usually considered insoluble in most traditional solvents. This property means that the selection of materials for seals, instruments, controls and other safety-critical components should be approached with great care. The use of pellets of solid carbon dioxide for heavy-duty surface scouring and scCO₂ for erosion cutting reflect the potential for high-pressure releases to cause serious harm to nearby structures, instruments or personnel.

133 When designing, fabricating and maintaining plant for handling and transporting carbon dioxide, it is important that the full significance of the differences between its physical properties and those of hydrocarbons, such as natural gas, is recognised. While this is especially important for dense phase CO₂ in view of the lack of specific standards, the properties of gaseous CO₂, especially that it is denser than air, should not be overlooked.

134 When considering releases from the dense phase, the intense cooling effect produced in the local area is a very serious hazard to instruments, electrical systems and the fabric of the installation, in addition to the danger from dry ice projectiles. Cryogenic embrittlement of structural steelwork and adverse effects from the impingement of extremely cold gas jets on safety-critical equipment (such as control, shutdown, detection and alarm systems) are major threats to the structural and functional integrity of nearby plant unless it is appropriately designed or protected.

135 Almost all the existing knowledge regarding the behaviour of dense phase carbon dioxide has been obtained from EOR operations and it is likely the injection pressures in future CCS projects will be a lot higher. It is very important that a detailed understanding is gained of the properties and behaviour of CO₂ at these higher pressures, particularly when a significant pressure change or accidental release occurs.

136 Carbon dioxide readily dissolves in water to form an acidic solution that is highly corrosive to many engineering materials. The accelerating effect this has on corrosion rates is a particularly important safety issue when considering the maintenance schedules and operating life expectancies for installations that were not originally designed as CCS projects.

Regulatory strategy

137 Aside from the regulatory controls described in Chapter 1, the regulation of CCS technologies depends on the regulatory approach to major hazard sites and pipelines described elsewhere in this report (see paragraphs 45 to 65, chapter 2). There are additional elements to the regulatory strategy described in paragraphs 138 to 144 below.

Exposure to substances hazardous to health

138 The Control of Substances Hazardous to Health Regulations 2002 (COSHH) imposes duties on employers to assess the risk to health from workplace exposure to hazardous substances. Where the assessment has shown a risk to health, employers must ensure that exposure is prevented or, where this is not reasonably practicable, adequate controls must be implemented and exposure monitored. Employees must be provided with information on the risks from exposure and trained in techniques to minimise these. Health surveillance may be required in situations where the risks are considered more serious.

139 COSHH applies to a wide range of chemicals and preparations with the potential to cause harm. It frequently provides controls for those substances not addressed by more specific legislation. Workplace exposure limits (WELs) are used to identify the maximum concentration of a substance to which an employee may be exposed. WELs have legal status under COSHH and are reviewed and published on a regular basis by HSC.

Occupational hygiene

140 All current indications are that the chemicals and materials likely to be used within CCS projects are covered by the COSHH Regulations and have published WELs. In addition, COSHH will also require assessment of the risk from contaminants present in CO₂ releases and arising from upstream processing or leached from process plant or geological formations.

141 Consequently, the existing regulatory framework is considered suitable and appropriate to control the occupational health risks arising from the foreseeable exposures to those substances likely to be encountered in CCS projects. Similarly, the other frequently encountered occupational hygiene hazards (for example, noise, vibration, stress etc) will also be effectively controlled through the existing legislative provisions.

Regulation of hazardous installations and land use planning

142 The hazard classification of carbon dioxide is such that it does not specifically attract the duties normally required for major hazard control under COMAH, the Planning (Hazardous Substances) Regulations 1992 or the Pipeline Safety Regulations 1996. Therefore, onshore installations and pipelines dedicated to handling very large quantities of carbon dioxide are currently outside the scope of the key pieces of legislation used to control those activities that present significant hazards. Carbon dioxide is not a specifically named substance, does not meet the

flammability criteria and is not identified as a dangerous substance by the underpinning Chemicals (Hazard Information and Packaging for Supply) Regulations 2002 (CHIP).

143 The regulations covering offshore installations do not depend on an appropriate CHIP classification and therefore would require duty holders to demonstrate that the risks from CO₂ were adequately controlled. However, the suitability of these regulations for CO₂ storage needs to be reviewed.

144 HSE will be required to comment on the risk presented at various stages in the lifetime of CCS projects if they are brought within the scope of planning legislation or are part of a currently regulated installation. The behaviour of carbon dioxide when released from the dense phase is not yet fully understood and there are currently no techniques available that can be used to accurately model the consequences. The industry will need to ensure that appropriate methodologies are developed to satisfactorily carry out this aspect of its duties and challenge the assessments put forward by duty holders. There is a need for appropriate scale experimental work to provide HSE and duty holders with a thorough understanding of the how CO₂ behaves during foreseeable large releases.

Standards

145 There are parts of the oil industry that have considerable experience of handling supercritical carbon dioxide. This knowledge is not, however, uniformly distributed, it is localised in areas such as North America where CO₂ has been used for several decades in EOR operations. These involve the annual long-distance transport of millions of tons of dense phase CO₂ by pipeline and its injection into depleted oil and gas reservoirs.

146 Notwithstanding the scale and maturity of EOR, there are few, if any, internationally recognised design and fabrication standards specifically for pipelines, pipework or fittings for scCO₂ duty. The British Standards Institution and the American Society of Mechanical Engineers (ASME) have each produced general standards for the design of pipelines for liquid hydrocarbons etc and these have been used as the basis for projects involving dense phase CO₂. The larger oil and gas companies have also developed their own in-house design and fabrication codes and protocols. There is also a wealth of technical information available in the literature and from the Internet.

Conclusion

147 Carbon capture and storage represents a challenging strategy for mitigating the effects of the ever-increasing use of fossil fuels on atmospheric carbon dioxide levels. To be effective, this approach must ultimately be on a huge scale, involving the annual capture and indefinite storage of millions of tonnes of CO₂ by each of the leading industrialised nations. These projects will be major undertakings that will involve moving current technology a considerable way forward.

148 These advances will be underpinned by a significant amount of 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 in this chapter will need to be recognised and addressed. These can be divided into three groups of issues, relating to research, standards, and review of the suitability of the existing regulatory framework to ensure that CCS projects are adequately covered.

149 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 need for modelling techniques to handle the complexity of behaviour following a leak or other loss of containment event must be addressed.

150 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 accurately predict the consequences of a major loss of containment event involving dense phase carbon dioxide. New models, methodologies and underpinning skills to perform the necessary assessments are needed to assess risks when CCS installations are proposed. This is best developed 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.

151 It is foreseeable that, in future CCS installations, the carbon dioxide injection pressures may be significantly greater than those in 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.

152 Second, the lack of internationally recognised standards and codes of practice specifically for dense phase CO₂ plant and equipment is a considerable 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 BSI and ISO, working together to address this important issue. Although the responsibility rests squarely with the industry, HSE will seek to facilitate progress.

153 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 the general management of health and safety, the established technology areas of major hazard sites, and occupational hygiene.

154 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.

4 RENEWABLE ENERGY SOURCES

155 There are many sources of renewable energy. Some, such as the use of photovoltaic solar energy, geothermal energy and hydroelectricity, present relatively few human health and safety risks or are already well understood and managed. This chapter concentrates on where we believe there are issues that merit discussion concerning health and safety issues.

A OFFSHORE WIND, WAVE AND TIDAL POWER

The technology

Offshore wind farms

156 The UK has a significant proportion of the total European potential for offshore wind resource, although to date only a very small amount of that potential is being tapped. The UK's first offshore wind farm, at Blyth, Northumberland, was commissioned in December 2000, and two larger wind farms, North Hoyle in the North West in 2003 and Scroby Sands off East Anglia in 2004, have subsequently come on stream. This gives a current total of around 124 MW generated from offshore wind power, around 0.1% of the total UK electricity demand. Further developments are waiting to be built under the DTI's first round of planning consents (over 1 GW), and a second round of planning consents has now been offered for offshore wind farm developments in north-west England, the Greater Wash, and the Thames estuary, with around 7.3 GW of generation anticipated.

157 Currently, offshore wind farms being built in UK waters are typically limited to 30 turbines each by the terms of the leases from the Crown Estate. This will increase though, with future generations of offshore wind farms and turbines being much larger than those built at present. Current offshore wind turbines have a maximum power output in the region of 3 MW, but machines of 5 MW capacity are entering production with even larger capacity models being designed.

158 Offshore wind farm construction is a relatively simple operation, with the turbines being of modular construction to facilitate rapid installation. Jack-up construction barges are used to transport components to site, drive piles, and erect the tower, nacelle (rotating section) and blades. Undersea cables connect the wind turbines to a focal point offshore where cables are run to a point onshore, and the generated power fed, via suitable transformers and infrastructure, into the national grid. Offshore turbines are designed for a life of 20 years.

Tide and wave power

159 Marine renewable technology is still at an early stage. HSE is not aware of any commercially significant developments, apart from a small 0.5 MW wave energy converter on Islay, Scotland. However, there is huge potential in wave and tidal energy, and a number of technologies are in the early stages of development, including marine current turbines and a variety of wave energy converter devices.

Health and safety risks

160 The offshore wind power industry is relatively low risk compared with the major hazard nature of offshore oil and gas. Currently the numbers of employees and contractors working in the industry is small, but estimates are for an offshore workforce of some 500 people by 2010.

161 The occupational hazards associated with offshore wind farms have been considered in a major risk study (*Offshore wind farms – risk review*). The principal hazards arise from:

- Construction and major repair: operation of jack-up construction barges and associated lifting operations during tower and nacelle erection. These health and safety issues may be more challenging in the future, as the new generation of wind turbines become significantly larger and taller.
- Operation (maintenance and minor repair operations): primary issues are access and egress (frequent personnel transfers between boats/construction vessels/towers), working at height, and emergency response. It is anticipated that each offshore wind turbine could require up to six maintenance or repair visits per year.

162 The potential external hazards to the operation of the wind farm come from marine and aviation activities. These matters are currently addressed by having the Ministry of Defence (MoD), the Civil Aviation Authority (CAA), the National Air Traffic Services (NATS) and the Maritime and Coastguard Agency (MCA) all as consultees to DTI in the consent process.

163 Although marine renewable energy generation via tide and wave power is much less developed, it is envisaged that it will present health and safety risks broadly similar to those arising from offshore wind farms.

Regulatory strategy

164 The HSW Act 1974, and appropriate subordinate regulations described in chapter 1 apply to offshore wind turbines and associated activities within the territorial sea adjacent to Great Britain (ie up to the 12-mile limit). This provides a suitable regulatory regime for health and safety.

165 However, the Act and regulations do not apply to wind farms or other energy structures outside the territorial sea, except when part of an existing offshore oil or gas installation. While existing wind farms are within the territorial sea, future farms may be built outside the 12-mile limit and would not attract GB health and safety legislation. A possible extension of the Act's application to cover any such future builds is being considered.

Standards

166 The British Wind Energy Association (BWEA) is the trade and professional body for the UK wind and marine renewables industries. BWEA has produced its own

Guidelines for health and safety in the wind energy industry, which includes best practice on design and specification across the manufacturing, construction, commissioning and demolition phases of a project.

167 The Marine Energy Network was established in 2005 by the University of Edinburgh's Energy Research Centre. One of its aims is to prioritise research activity in marine renewable energy and in the future there may be health or safety research or standards arising from the Network's activities.

Conclusion

168 The existing regulatory arrangements are sufficient to deal with an expansion of energy production from offshore wind, wave and tidal. However, the potential lacuna relating to offshore wind farms beyond 12 miles (see paragraph 165) is noted, and if developments this far from the coast are likely, the legal requirements will be reviewed.

B ONSHORE WIND POWER

The technology

169 Onshore wind turbines represent the largest contributor to electricity generation from renewable sources in the UK. The amount of power generated from wind energy surpassed 1 GW in 2005, the majority of which came from onshore turbines. However, if onshore wind remains the main source of renewable energy, it will be required to deliver more than 4 GW of capacity to ensure that the Government's renewable energy targets are to be met (10% electricity generated by 2010).

170 Turbines in the capacity range of 1–2.75 MW are connected with the National Grid at transmission voltage (ranging from 132 kV to 400 kV) and the distribution network systems (ranging from 11 kV to 132 kV) run by private network operators. Connection at this level renders renewable wind energy as 'distributed' generation (see chapter 5). There are, at the time of preparing this report, 121 operational onshore wind farms representing over 1400 individual wind turbines (April 2006). There is also a potentially significant market for small wind turbines connected at 230 V in domestic and commercial premises, usually in the form of single discrete units, with capacities of a few kilowatts of microgeneration.

Health and safety risks

Risks to employees

171 The wind industry has developed on a global scale and the risks associated with this technology are well known. The work associated with the fabrication, installation, operation and decommissioning does not present major hazards to the workforce. The installation and decommissioning risks are similar to those found in

other engineering activities such as construction and the use of cranes. Operational risks, including routine maintenance, are similar to those encountered in small conventional power stations and the electricity transmission and distribution industry. The main industry trade association, the BWEA, has established widely-used *Guidelines for health and safety in the wind energy industry*. These identify the hazards and provide guidance on their management. HSE has been actively involved in the production and revision of these guidelines.

Risks to the public

172 Wind turbines are frequently located on land open to the public and so account needs to be taken of hazards such as whole or partial blade failure, falling ice, fire and lightning. The history of the industry indicates that the likelihood of occurrence of incidents from these hazards is low. When the developer seeks planning permission for the wind farm, these potential risks to public safety should be assessed within the planning framework process.

Microgeneration

173 The increased use of small microgeneration turbines presents new challenges. These could be placed on buildings, which leads to the need to address potential problems with mounting structures, load bearings, building integrity, vibration and proximity to the public. The standards of training for those involved would need to be high. This emphasises the importance of the introduction and application of the principles within the Government's new Low Carbon Buildings Programme and the DTI's Microgeneration Programme. BWEA and HSE are currently reviewing this area and will be making recommendations with the aim of developing and promoting suitable guidance and standards for the industry.

Regulatory strategy

174 HSE's main responsibilities relate to the legislation aimed primarily at protecting the health and safety of those at work, and includes installation, operation, maintenance and decommissioning activities.

175 The DTI Engineering Inspectorate is currently responsible for the safety of the public as regards mechanical dangers, such as blade failure, icing and fire. The allocation of responsibilities between DTI and HSE, and those of other bodies, is outlined in an appendix to the Memorandum of Understanding between HSE and DTI. Following implementation of the recommendations of the Hampton Report (*Reducing administrative burdens: Effective inspection and enforcement*) on regulatory enforcement, the responsibility for both public and worker safety will fall solely to HSE. As such, HSE will become the principal regulator dealing with all health and safety issues in the wind power generation industry.

176 HSE will continue to promote the adoption and application of sensible risk management policies through working with the trade association to keep the BWEA Guidelines up to date. HSE will encourage the use of best practice and common standards, high-quality training and adoption of the wind turbine safety rules along

with the promotion of other health and safety initiatives and guidance. This reflects a desire by both parties to adopt a responsible attitude to health and safety, which is essential if the wind industry is to be successful.

177 However, the planning process also has an important role to play in helping identify and address health and safety issues prior to development and construction, such as turbine location. This will ensure effective risk control for the phase prior to HSE regulatory responsibilities for worker safety with respect to the installation, operation, maintenance and decommissioning of the equipment becoming operative. Current planning guidance places an emphasis on environmental, social and economic issues, but health and safety issues affecting both employees and members of the public also need to be properly considered at this early stage. Full consideration of issues such as turbine location relative to other structures, highways and areas where the public have access will help ensure the continued safe development and reputation of the wind industry. The application of sensible risk assessment as an integral part of the planning process should help identify significant risks and highlight any measures required to reduce them to an acceptable level.

Standards

178 The use of wind turbines is subject to various standards and guidance, issued by both Government and industry.

179 BS 61400-1: 2004 *Wind turbine generator systems (safety requirements)* and BS 61400-2: 1996 *Safety of small wind turbines* are the two principal, current national standards. There are also a number of associated standards dealing with protection and testing requirements (structural, load, power output etc). The original Part 1 standard was issued in 1995 and is the English version of the European Pre-standard of the same title, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 1400-1: 1994 published by the International Electrotechnical Commission. Part 2 is identical with IEC 1400-2: 1996. A Commission Maintenance Team is responsible for any revisions to the IEC standard and BSI is the UK representative here.

180 These standards specify requirements for the safety of onshore wind turbine generator systems irrespective of location or environment, including design, installation, maintenance and operation under specified environmental conditions. They also cover all subsystems, including control and protection mechanisms, internal electrical systems, mechanical systems, support structures, foundations and the electrical interconnection equipment. The standards are concerned with quality assurance during design and manufacture and also with the adequacy of the assembly, installation, maintenance and operational procedures.

181 The framework for national planning policy for England and Wales is Planning Policy Statement 22 (PPS22) *Renewable energy* and comes with a companion guide which contains technical advice and guidance on renewable technologies and examples of good practice for development plans. It excludes hazards associated with aircraft impact, which are covered by aviation regulators, but

it does recognise hazards arising from proximity to roads, railways and public rights of way, ice throw, structural failure and road driver distraction.

182 Further guidance exists for Wales in Planning Policy Wales document TAN8 *Planning for renewable energy*. For Scotland similar guidelines exist in NPPG 6 *Renewable energy developments*, and PAN 45 *Renewable energy technologies*. All consider wind technology to be safe if properly designed, erected and maintained.

183 As mentioned previously, guidance has also been issued by the wind industry. BWEA, the trade and professional body, has recently revised its document *Guidelines for health and safety in the wind energy industry*. This took account of recent experience within the industry, principally in offshore developments. Other BWEA guidance, *BWEA Best practice guidelines*, leads potential developers through planning and environmental legislation. It recommends that developers discuss plans with HSE operational staff as necessary regarding structural integrity and assessing the risk to public safety.

184 Much of the content of the BWEA health and safety guidance is applicable to small-scale wind turbines, but other more specific industry guidance exists, such as the *Energy efficiency best practice guidance on installing small wind-powered electricity generating systems*.

Conclusion

185 The risks to those who work in the onshore wind energy industry are adequately dealt with by existing health and safety legislation. The current level of health and safety incidents is low in this sector in relation to the number of turbines and the growth of the industry. The industry is taking a proactive approach to safety through its trade association (BWEA) and the HSE will continue to support this.

186 Some risks to members of the public are best addressed through planning controls as well as health and safety legislation. The promotion of clear guidelines and their application by planning authorities to deal adequately with risks to the public, relevant standards and industry good practice, should minimise the risks to both employees and the public. This will also ensure a consistent approach from those who currently assess the development of wind farm sites and those who undertake reactive regulatory enforcement. HSE will continue work with all relevant parties to facilitate the production and maintenance of such guidelines.

C BIOMASS

The technology

187 Biomass can be considered as a form of stored solar energy. The energy of the sun 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 (from municipal and commercial sources, sewage, and food and animal wastes).

It is a versatile source of energy which can be used to produce heat, electricity, fuel gases and fuel liquids.

188 Use of biomass follows these main routes:

- direct combustion, either alone or ‘co-fired’ with other fuels such as coal, usually to produce electricity using steam turbines. The ‘heat energy’ may be used in processes, or possibly in district heating schemes. Worldwide experience suggests that ‘heat energy’ is the dominant product from biomass;
- pyrolysis/gasification processes are used to produce fuel gases and liquids and also generate heat for process use or export. Synthesis gas produced by biomass gasification can also be converted to hydrocarbon liquids using Fischer-Tropsch synthesis. It is also a route to produce hydrogen or charcoal;
- fermentation/distillation processes are used to produce bioliquids such as bioethanol from sugars and other biomass;
- esterification/transesterification processes to produce ‘biodiesel’ from vegetable oil;
- digestion processes acting on residues and wastes to produce biomethane. Landfill gas has been particularly significant in the UK.

189 All of these routes have been in use for decades and some for centuries although their commercial significance has varied over time particularly due to the influence of cheaper oil- and gas-based products.

190 Energy from biomass is usually regarded as carbon neutral rather than carbon free. The production of energy from biomass at fixed sites can be combined with carbon capture and storage to turn it into a carbon remediation process.

Health and safety risks

191 We discuss in detail, in paragraphs 192 to 206, a number of different biomass processes in the context of health and safety risks.

Biomass storage and handling

192 Biomass in storage clearly presents a fire risk when dry. In small particle sizes, for example after size reduction prior to direct combustion or pyrolysis/gasification, there is an explosion risk when dispersed in air.

193 In addition, the material used for biomass processes does not always store well. It may give off odours, and produce spores and foul liquids, which may have the potential to affect health. It could thus give rise to health risks and consequently requires handling with care and close consideration of containment measures.

Pyrolysis processes

194 Pyrolysis (or devolatilisation) processes take a biomass fuel and chemically decompose it by heating in the absence of oxygen or any other reactant. It produces hydrogen, methane and tars and leaves a residue commonly called a char. Taken to

completion, the char is mainly carbon. In many industrial applications, the process is done under pressure and at operating temperatures above 430 °C.

195 Pyrolysis can also be used to produce liquid fuel similar to diesel from solid biomass. The most common technique uses very low residence times (<2 seconds) and high heating rates using a temperature between 350–500 °C and is called either fast or flash pyrolysis.

196 Pyrolysis processes involve flammable gases being handled at high temperatures and, optionally, moderate pressures. They can also involve a hot heat transfer medium such as sand. The handling of flammable gases under these conditions is relatively well understood. One issue is the variability of the flammability of the pyrolysis gases due to wider variability of gas composition when compared with pyrolysis of fossil fuels.

197 Pyrolysis processes are often an immediate precursor to gasification.

Gasification processes

198 Gasification processes take a char and react it with oxygen and steam to produce carbon monoxide and hydrogen. The resulting gas is called producer gas or syngas (or wood gas when derived from wood) and may be more efficiently converted to energy such as electricity than would be possible by direct combustion of the fuel, as the fuel is first combusted in a gas turbine and the heat is used to produce steam to drive a steam turbine (IGCC or integrated gasification combined cycle).

199 Several designs of gasifier are available, all operating at high temperatures (greater than 700 °C). Gasifiers can operate at ambient pressure or above.

Fermentation processes

200 Fermentation typically refers to the conversion of sugar to alcohol using yeast. The process is often used to produce or preserve food, typically wine or beer. The alcohols produced can also be used as liquid fuels. Fermentation processes are well understood, having been practiced in history as far back as 5000 BC. When yeast ferments, it breaks down the sugar ($C_6H_{12}O_6$) into exactly two molecules of ethanol (C_2H_6O) and two molecules of carbon dioxide (CO_2). The CO_2 is typically released to atmosphere. The fermentation process is usually carried out at ambient temperatures and pressures and presents no significant safety risks.

Distillation processes

201 Distillation processes have been known for as long as fermentation processes as the two often are encountered together. There is a range of distillation processes that are encountered in industry, operating continuously or batchwise, separating a feedstock into two or more fractions. Distillation to produce biofuels uses the simpler distillation processes and the safety issues are those associated with the handling of flammable liquids and vapours and above ambient temperatures and possibly elevated pressures.

Esterification/transesterification processes

202 Esterification is the general name for a chemical reaction in which two chemicals (typically an alcohol and an acid) form an ester as the reaction product. Transesterification is a reaction to transform one ester into a different ester. Some esters are useful liquid fuels. These processes are not particularly exothermic, do not require extreme process conditions, and are straightforward to control.

Fischer-Tropsch processes

203 These date from discoveries in Germany in 1923. The Fischer-Tropsch process is a catalysed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms for use as liquid fuels or chemical feedstocks. They are catalytic reactions at elevated temperatures and pressures. Over the years, the problems in operations have been issues such as reaction selectivity and catalyst poisoning rather than safety issues. These gas-to-liquids plants came to the fore during wartime, and in South Africa when sanctions were applied. Although less prominent than oil refining, gas-to-liquids plants are still operated by major oil/chemical companies and the safety issues are well understood.

Digestion processes

204 In sewage disposal, sewage is digested by enzymes secreted by bacteria. Solid organic matters are broken down into harmless, soluble substances and carbon dioxide. Liquids that result are filtered to remove pathogens before being discharged into rivers or the sea, or can be used as liquid fertilisers. Digested solids, known also as sludge, can be dried and used as fertilisers. Alternatively they can be used to generate fuel gases in gasification processes.

205 The CO₂ is typically released to atmosphere. Methane generated can be used alone or in combination with fuel gas generated by gasification of the dried sludge to power internal combustion engines or turbines. The safety issues associated with high temperatures and pressures are similar to pyrolysis/gasification processes already described. Methane may also be stored in low-pressure gas holders before use. These are similar to the widely encountered gas holders used for natural gas, and previously town gas.

Downstream processes

206 The safety issues arising from the downstream aspects of energy from biomass are generally very similar to equivalent products/processes from fossil resources. For example, requirements for the safe operation of gas turbines, safe storage and handling of flammable liquids, are well known.

Regulatory strategy

207 As with safety generally, there is a hierarchy of risk control measures that are applied to these processes. These are:

- inherent safety: including the avoidance of hazardous substances/conditions or substitution by less hazardous substances/conditions during design;
- prevention: measures which are built into a design that are functioning all the time;
- control: measures which are built into a design that start to function at the onset of a process upset; and
- mitigation: measures which reduce the impact of an event following failure of prevention and control measures.

208 Inherent safety is a well-established concept that has proved to be elusive in many areas of the process industries. Processes are frequently well established, and research for and adoption of inherently safer process routes has often proved to be too big a business risk.

209 Prevention and control measures form the core material of relevant good practice precautions (codes and standards). In years gone by, standards and codes were often instigated as part of the response to accidents. More recently the measures included in codes and standards have been determined by the prior application of hazard and risk analysis techniques before the widespread adoption of plant, equipment, or a new technology.

210 Mitigation includes the provision of measures such as fire-fighting arrangements, and for large chemical sites, control of nearby development to manage risk to adjacent people (and the natural and built environment).

211 Overall the approach for flammables is to prevent loss of containment and, if it does occur, to have managed the location of ignition sources so that modest-sized releases are not ignited, and if releases are ignited, to have managed the numbers and locations of people nearby.

Standards

212 There are a number of safety standards applicable to these processes. They range from the very general, such as those pertaining to the design construction and operation of pressure systems, to the specific, such as bursting discs and pressure relief valves that form part of pressure systems.

213 Some trade/professional bodies develop and publish applicable standards. For example, the Institution of Gas Engineers and Managers publishes IGE SR4 *Low pressure gas holders – lighter than air gases*. This is applicable to the storage of fuel gases at low pressure.

214 In some cases the particular plant designs are proprietary and do not exist in sufficiently large numbers to attract the attention of the standards-making bodies. In

these cases, the knowledge of safe design and operation resides with the chemical engineering contracting companies and is derived using techniques such as HAZOP and HAZAN.

Conclusion

215 None of these processes are particularly novel and therefore do not require a change to current regulatory arrangements or strategy. Clearly there are training/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 use of fossil resources for energy needs.

5 DISTRIBUTED GENERATION

The technology

216 Distributed generation is the move of power generation closer to the consumer. To increase efficiency further, such generation is often, but not always, combined with heat generation. A large number of privately owned power plants with outputs from 0.5 MW to 50 MW have already been built to provide electrical and thermal energy to local factories or amenities. The future will see an increasing penetration of medium to very small power generation sources, many operating in combined heat and power (CHP) configurations. The overriding rationale for the move from centralised to distributed generation is the reduction of transmission losses and the suitability of new and renewable energy sources in the 1 kW to 5 MW range.

217 Chapter 4 describes the contribution of renewable sources (wind, biomass) to distributed generation. In addition, a variety of devices with electrical outputs in the 0.7 kW to 200 kW range are now in states of development that range from pre-production prototypes to in-service. These devices include novel applications of conventional technology, described further in paragraphs 221 to 232, and fuel cell technology powered by hydrogen, hydrocarbon or methanol fuels.

218 There is considerable worldwide interest in the use of hydrogen as a significant future energy carrier (enabling energy to be conveniently moved from one point to another). The phrase ‘hydrogen economy’ is now widely used to describe a future scenario in which hydrogen and related technologies play a significant part in powering the devices necessary for a healthy economy and enjoyable personal lives. The hydrogen economy is centred on releasing the energy stored in hydrogen either through direct combustion, or more efficiently, through its use in fuel cells.

219 The four main technologies used in distributed generation are external combustion (EC) engines, internal combustion (IC) engines, gas turbines and fuel cells. These can also be operated in CHP configurations. CHP is a highly fuel-efficient energy technology where the simultaneous production of heat and power can almost double the overall efficiency of fuel use when compared to that of electricity generation plants burning fossil fuels. Such configurations are suited to providing the thermal and electrical energy requirements of individual homes, multi-occupancy buildings, hotels and neighbourhood communities.

220 We discuss a number of specific applications in paragraphs 221 to 241.

External combustion (EC) engines

221 EC engines maintain a working fluid inside the system that is heated by an external source. The working fluid drives machinery to produce power, then it is cooled ready for reheating. EC engines are theoretically compatible with any fuel, since the heat source is external to the working fluid cycle. Most are currently designed to run on natural gas but LPG or fuel oil-fired EC engines would open up the market to geographical areas without natural gas. Current developments include the Stirling engine and systems based on the Rankine cycle.

Stirling engine

222 The Stirling engine was invented in 1816 but only recently has mass production seemed likely. In the UK, 400 domestic-scale (approx 1 kW_e) Stirling engine units from one manufacturer have been on trial, with the design recently becoming available on a commercially produced scale. A second manufacturer is expecting to trial its domestic-scale product in 2007.

223 Hydrogen and helium are among the best working fluids because of their high heat capacity and a low viscosity. Current designs for domestic units use nitrogen or helium. The typical working fluid pressure for a micro-CHP 1 kW_e unit is 20–30 bar.

Rankine cycle system

224 CHP units based on Rankine cycles are under development. The Rankine cycle is the basis for the steam engine and water is the traditional working fluid. By using organic chemicals (such as pentane, butane, propane or ammonia) as the working fluid the system can operate at lower pressures.

Reciprocating internal combustion (IC) engines

225 Large IC engines have been commercially available for many years. A 5 kW_e IC engine, aimed at the commercial market, is currently being marketed in the UK but has been available in Germany for some time. In Japan, a few thousand 1 kW_e IC engines have been installed, but in the UK, IC engines do not seem to be targeted at the domestic market.

226 In reciprocating IC engines, fuel combustion takes place in a cylinder, producing expanding gases that are used directly to provide mechanical power. In each cylinder, a piston slides up and down. A rod connects the bottom of the piston to a shaft and the reciprocating (up-and-down) motion of the piston rotates the shaft. The fuel/air mixture is ignited at the top of the cylinder.

227 Larger IC engines are often used as a primary electricity source or as a local back-up generator. However, the IC engine is increasingly used in CHP configurations with the exhaust gas used as a source of heat for a process, or to produce steam or hot water. By adapting the air/fuel mix, IC engines can run on different fuels: most commonly diesel, natural gas, LPG and fuel oil. For larger applications, the heat recovery equipment is sometimes supplied separately.

Gas turbines

228 Gas turbines are increasingly and widely used for power generation worldwide. The engineering principles behind their design are those used for jet engines. They are capable of burning almost any gaseous or liquid fuel and can usually change fuel without operational interruption. The majority include means of using heat from the engine exhaust to increase efficiency.

229 The gas turbine has a single rotating shaft carrying blades. High-pressure fuel is mixed with high-pressure air and burned to produce a large volume of high-pressure hot gas. The gases are used to drive additional turbine blades and the engine produces rotational energy that can be used to drive a generator and produce electricity.

230 Gas turbines for power generation are available over a wide range from below 50 kW to above 300 MW.

231 Often gas turbines are used in CHP configurations, and as for the IC engines, heat recovery equipment is sometimes supplied separately. With gas turbines in the approximate range 3–60 MW, they are generally suitable for commercial or industrial sites where there is a reasonably constant demand for heat that the plant can meet, and/or where the excess electricity and/or heat can be exported.

232 Microturbines have been developed for power generation often in CHP configurations. However, the electrical output, 50–300 kW, and heat output of similar magnitude, are too large for domestic applications. The smallest machines are about the size of a hot-drinks flask, in a package the size of a small wardrobe. In the USA and Japan in particular they are now installed in hundreds, but have not yet met with wide acceptance in the UK. They have been used in very small numbers, a few tens, for city blocks, sports complexes, agricultural applications, shopping malls, stand-by emergency power sources, etc.

Fuel cells

233 A fuel cell is a device similar to a battery that never becomes flat. So long as it is fed with hydrogen or a hydrogen-rich chemical, it will continuously convert the chemical energy present in the fuel into electrical energy. Pure water is the only by-product from the process in which the hydrogen in the fuel combines with oxygen from the air.

234 Fuel cells can be used to provide electricity on a small scale for individual portable devices, to power vehicles or as stationary units providing the basis for CHP units or standby sources for homes and businesses. In these latter applications, they will range in size from very small domestic units with outputs of a few kilowatts to medium-sized installations providing a few megawatts of power.

235 Over 250 large (200 kW) fuel cells are already in use around the world providing electricity and heat to businesses and municipal facilities. The number of these units is expected to increase rapidly as manufacturing costs are reduced. Most large stationary fuel cells run on natural gas, which the fuel cell converts to hydrogen before use in the production of electricity. This approach to distributed electricity generation is more efficient and produces less carbon dioxide than methods involving the combustion of natural gas.

236 Similar but much smaller units manufactured by UK companies are now undergoing demonstration trials in domestic households. Further into the future, the use of fuel-cell vehicles as contributors of electrical power to local networks when not

being used for transportation has been predicted as an element in a fully developed distributed generation scenario.

Hydrogen

237 Fuel cells use hydrogen, which can be produced from many sources by a variety of different technologies. The use of hydrogen as a fuel is not new; town gas, which was used for almost a century as a major UK fuel until the 1950s, comprised over 50% hydrogen. Production technologies include those that have been in use for over 50 years, those developed recently, and others whose feasibility has yet to be demonstrated outside the laboratory.

Hydrogen production

238 Most of the hydrogen currently produced results from steam reforming, gasification or electrolysis. All are relatively mature and well-understood processes and their hazards are also well understood. Steam reforming and gasification are described in chapter 3. Electrolysis uses electricity to split water into its constituent elements, hydrogen and oxygen. This is very energy intensive and is currently commercially viable only where electricity is very cheap. However, electrolysis could become enormously important in the future when linked to renewable energy sources such as wind, solar, tidal etc. High-efficiency high-pressure alkaline electrolysis units are becoming commercially available. It is foreseeable that the widespread deployment of small- and medium-scale electrolysis units will be a significant feature of a medium-future distributed energy infrastructure.

239 Several types of algae and bacteria can produce hydrogen by modified photosynthesis or fermentation processes. Most are currently at the research and development stage.

Hydrogen storage and transport

240 Hydrogen contains more energy on a weight-for-weight basis than any fuel; however, its energy content on a volume basis is very low and this is a major obstacle to the use of hydrogen in vehicles and portable devices. Three general methods are available for storing hydrogen:

- Compressed gas: Most hydrogen is stored and transported as a highly compressed gas at pressures around 200 bar. This is likely to continue to be very important in the hydrogen economy, but pressures of around 1000 bar will be required.
- Liquefied: Hydrogen can be stored as a liquid in highly insulated pressure vessels, at a very low temperature (minus 253 °C). The energy required to produce liquid hydrogen and the inevitable boil-off losses are considerable disadvantages, but these are offset by the high volumetric energy content of liquid hydrogen for some applications.

- Chemical storage can be divided into three approaches:
 - storage in solids, such as metal alloys and compounds that have an enormous affinity for absorbing hydrogen but will also release the captured hydrogen on demand. This is one of the most active areas of current research;
 - the use of liquid fuels, such as methanol, that are rich in hydrogen. Methanol is a concentrated, highly portable source of hydrogen that can be used directly by certain types of fuel cells. Methanol is likely to be used extensively in very small fuel cells used to power portable devices such as laptops and phones, but is unlikely to be important in distributed generation. When methanol is used to power fuel cells, carbon dioxide is a by-product;
 - the use of reactive chemicals to release or produce hydrogen when required. This approach is attractive for relatively short duration, high value applications where cost is not a significant priority.

241 Hydrogen is currently transported as a gas in dedicated pipelines, pressurised cylinders and as a cryogenic liquid in large insulated flasks. These are likely to continue as the principal methods of transport. However, in preparation for the medium-term future, considerable work is being carried out to examine the feasibility of distributing hydrogen through the existing natural gas pipeline infrastructure. If successful, this work would provide a mechanism to supply increasing amounts of hydrogen to all parts of the UK without the need to build a new distribution system.

Health and safety risks

Human health risks

242 The fuels used for distributed generation are non-toxic with the exception of methanol (used for fuel cells), a highly flammable liquid that is toxic by ingestion, inhalation and skin absorption.

243 However all hydrocarbon gas-burning appliances have the potential to produce unsafe quantities of toxic carbon monoxide if insufficient air is available for the air/fuel mixture or if the appliance is not working correctly. The exhaust gases for distributed generation equipment are usually vented outside via exhaust ducting, or in the case of domestic appliances, via a flue. The hazards of carbon monoxide are well documented and the risks are no greater than for a conventional gas boiler.

244 Stirling engine working fluids, such as helium and nitrogen, pose an asphyxiant hazard, but this hazard is reduced by using small quantities and by adequate ventilation. In addition, some working fluids that may be used in an organic Rankine-cycle CHP unit are toxic, eg ammonia.

245 The hazards associated with the hydraulic oils, lubricants, cleaning substances, fuel additives etc, are moderate, well known, and generally well controlled.

246 Gas turbines are installed within acoustic enclosures, simply because they are so noisy that they cannot be allowed to operate otherwise, IC engines are also sometimes installed within acoustic enclosures to reduce the noise to an acceptable level. Prolonged entry to enclosures is hazardous because of the high temperature, noise and confined space issues.

247 Entry into turbine enclosures thus requires strict observance of controls to prevent accidental asphyxiation from carbon dioxide, the normal fire suppression medium that would be activated in the event of a fire. In an international context, water mist has been tested and shown to be a very successful fire suppressant for this application, and its use is rapidly increasing.

248 In summary, the health risks from distributed generation are noise, exposure to substances and asphyxiation. However, these risks are well understood and adequately controlled.

Safety risks

249 Foreseeable safety hazards associated with the use of a CHP unit include: fire and explosion, pressure release, moving parts, hot surfaces and electric shock. The novel and often complex nature of the equipment needs to be recognised in the training and qualification of competent people, and in installation and maintenance procedures. This is especially important in the domestic and commercial sectors, where the non-technical background of the typical users would be a consideration. Competency will be required in plumbing, electrical and gas fitting to install units. However, CORGI registered installers with the required qualifications and experience must install domestic and commercial units.

250 Moving parts and hot surface hazards are dealt with by enclosure; CHP units for domestic use are housed in a cabinet much like a conventional boiler, and moving parts are deep within the system. As discussed in paragraphs 246 to 247, gas turbines are housed within acoustic enclosures to prevent normal access to these hazards.

251 External combustion engines also have hazards associated with the working fluid such as fire, explosion and overpressure. EC engines can be made inherently safer by choosing a safer working fluid, ie non-toxic and non-flammable, for instance helium over hydrogen for Stirling engines. The internal working fluid circuit should be protected from foreseeable overpressure, for example, by a pressure relief device relieving to a safe place.

252 Fires and explosions within the equipment itself (for example, within the turbine or engine, its exhaust stack or within the associated heat recovery equipment) are foreseeable, with injury potential to those in the vicinity. Such fires and explosions are caused by a failure with the equipment or part of its control system allowing a delayed ignition. Where the heat recovery equipment is supplied separately it is important to ensure that the exhaust pipework, between the engine outlet and heat exchanger inlet, is as short as possible and that this volume is taken into account when purging the engine.

253 A leak of a liquid fuel or oil, or gas may ignite from the hot surfaces or from other sources. Fires are more common, but explosions, while rare, may have far greater consequences.

254 A key feature of a distributed generator is its control system. This must be able to control the burner and engine according to inputs such as heat and electricity demand, flue temperature and composition, and coolant temperature. It must have routines built in for safe shutdown in the case of the maloperation and be able to cope with a power loss. It should have shutdown routines and alarms, and trips when air, exhaust or temperature limits are passed.

255 An electric shock from a live electrical connection from any generator (whatever the source) is also a hazard to those carrying out work on or near to the distribution network. Current good practice calls for isolation of all supplies and proof that they have been isolated. This will not change with the advent of more distributed generators, but could be harder to determine. There will be a greater need to ensure personnel competence and the availability of accurate information on the likelihood of more than one live feed.

256 Gas turbines within acoustic enclosures bring about additional risks. 'A jet engine in a box' together with its high-pressure fuel supply, and lubrication and hydraulic systems, presents obvious and easily foreseeable fire and explosion hazards. The pipework systems are complex, and a leak of a liquid fuel or oil, or gas, may and often does ignite from the hot turbine surfaces or from other sources. Fires are not uncommon, but explosions, while rare, may have far greater consequences and potential for injury. The risk of fire is relatively high, but the industry has reduced the risks to humans very effectively and has a good overall injury record

257 The hazards of enclosed high-speed rotating gas turbines arise from the loss of containment in the event of damage to the rotating parts. The hazards arising are the same as those associated with aircraft turbines with fewer people likely to be affected, but the incident can escalate if the blades cause damage outside the turbine or even outside the enclosure.

258 In general, the risks associated with microturbines are of a lower magnitude, but otherwise the same. The fuel pressure is lower, but the speed is far higher (100 000+ rpm). The incident history is very low, but so is the population.

259 Like most fuels, hydrogen is flammable, and mixtures of the gas with air across a very wide range of concentrations will explode extremely violently when ignited. The recognition that hydrogen has some properties (for example, high buoyancy, very low viscosity, embrittlement of certain metals, very high flame speed and significant possibility of detonation) that are unique will be very important as the use of hydrogen in new environments accelerates. It will not be appreciated that specialised competences are required and inappropriate decisions will be made in the workplace regarding the transferability of skills from traditional fuels to hydrogen if this message is not effectively communicated.

260 In summary, the safety risks are fire, explosion, pressure release, moving parts, hot surfaces and electric shock.

Regulatory strategy and standards

261 Control of the risks is by the application of standards and by regulatory controls, the latter comprising general controls under health and safety at work law described elsewhere in this report and more specific controls described in this section.

262 European Union (EU) product Directives specify essential safety requirements (ESRs) considered necessary to minimise the risk from the hazard covered in that Directive. The product Directives are implemented in national law through regulations. HSE enforces some product legislation in the workplace, while in the non-work environment this falls to the Trading Standards Authorities.

263 The Gas Appliances (Safety) Regulations 1995 (GASR) apply to gas-burning appliances used for cooking, heating, water heating, refrigeration, lighting and washing with, where appropriate, a normal operating temperature not exceeding 105°C, but excluding appliances which are specifically designed for use in industrial processes on industrial premises. GASR defines 'gas' as any substance that is gaseous at 15 °C and 1 bar, for example natural gas, LPG, and hydrogen. Distributed generation equipment would be so classed where its main purpose is the production of heat for other than process applications and the electricity production is ancillary.

264 The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996 (EPS) are primarily concerned with products, both electrical and mechanical, intended for use in potentially explosive atmospheres arising from flammable substances in the form of gases, vapours, mists or dusts. They do not cover equipment intended for use in domestic and non-commercial environments where a potentially explosive atmosphere may only rarely be created, solely as a result of the accidental leakage of fuel gas. EPS would, however, apply to all distributed generation equipment used in commercial and industrial premises.

265 The Supply of Machinery (Safety) Regulations 1992 (SMR) cover machinery, which is defined as having at least one moving part within the assembly of linked parts. The product also needs to have a specific application, such as processing etc. Therefore distributed generation units with moving parts would be covered by SMR unless all the risks presented by machinery are wholly covered by other EU legislation. However, in practice there is often overlap with other directives, and the European Commission have advised that two (or more) sets of implementing legislation may be applied.

266 Pressure Equipment Regulations 1999 cover equipment designed to contain pressures above 0.5 bar unless all the risks presented are wholly covered by other EU legislation.

267 The Electrical Equipment (Safety) Regulations 1994 (EESR) apply to electrical equipment operating between voltages of 75 and 1000 volts AC or 100 and 1500 volts DC, so the supply of most electrical equipment will fall within scope of EESR.

268 The Gas Safety (Installation and Use) Regulations 1998 (GSIUR) apply to the installation, maintenance and use of domestic and commercial gas appliances but it does not include equipment used as part of an industrial process on an industrial premise. 'Gas' has a similar meaning under these Regulations as for GASR (see paragraph 263 above), except that GSIUR does not include gas consisting wholly or mainly of hydrogen when used in non-domestic premises. HSE and local authorities enforce these Regulations.

269 The Provision and Use of Work Equipment Regulations 1998 would apply to the installation, maintenance and use of work equipment including distributed generation equipment.

270 Specific standards relating to a number of specific applications are discussed in paragraphs 271 to 281.

External combustion (EC) engines

271 In common with many developing technologies, there are no design standards, nationally or internationally, for EC engine units. However, product legislation must be complied with.

272 A number of British Standards covering the installation of domestic gas appliances are equally applicable to an EC engine CHP unit and similarly, the Institution of Gas Engineers and Managers (IGEM) produces several technical publications that are relevant.

Internal combustion engines

273 A number of European standards cover design aspects of reciprocating IC engines and associated generating sets; applicable design safety standards include BS EN 1679-1, BS EN 1834 and BS EN 12601. Standards of this type are not compulsory but the equipment must comply with the ESR's of the relevant product legislation.

274 A number of British Standards cover the installation of domestic gas appliances and similarly, the Institute of Gas Engineers and Managers (IGEM) produces several technical publications that are relevant, in particular IGE/UP/3 *Gas fuelled spark ignition and dual fuel engines*.

Gas turbines

275 The main gas turbine procurement standard, ISO 3977, in nine parts, contains a page of generic safety requirements and limited references to safety. In the late 1990s, HSE recognised the dearth of safety-related guidance and, following several major incidents, published PM84 *Control of safety risks at gas turbines used for power generation* in 2000 (revised in 2003). PM84 was the first comprehensive guidance in the field; it has become widely accepted and is used worldwide.

276 In 2000, IGEM published IGE/UP/9 *The application of natural gas fuel systems to gas turbines and supplementary and auxiliary fired burners* giving detailed

fuel system guidance specific to gas turbines. This was revised in 2004 to include liquid fuels.

277 A new ISO standard, ISO 21789, is currently in preparation. The standard covers all the known hazards associated with these machines so far as their control is within the scope of the manufacturer or supplier. It does not deal with maintenance or use, and PM84 will remain the only guidance on these aspects. Its scope covers the more common fuels (natural gas and fuel oil) and the most common applications.

278 An information document (OC482/7) is available from HSE covering the health and safety risks of gas turbines under 1.2 MW. Its scope excludes domestic applications.

Fuel cells and hydrogen

279 The use of hydrogen in traditional applications and environments is well supported by UK, EU and international codes and standards produced by bodies such as British Compressed Gases Association (BCGA), European Industrial Gases Association (EIGA), National Fire Protection Association (NFPA) etc. The situation with regard to hydrogen economy applications in the UK is less well structured but improving. With the exception of HSE's guidance document HSG243 *Fuel cells*, which is aimed at designers and users, there is currently little UK-specific guidance on the use of hydrogen in hydrogen economy applications. There are, however, several initiatives currently underway to address this, including two pan-European projects ('HyPer' concerning guidance for stationary applications, and 'HySafe' concerning safety of hydrogen in widespread applications, including public use) in which HSE is actively involved. A lot of work has also been done in the USA in this area and will provide a sound basis for the development of a UK framework. The UK Hydrogen Association, CORGI and HSE have been working to produce a code of practice for the installation of hydrogen fuel cells.

280 A number of bodies are developing codes and standards for the hydrogen economy including the International Standards Organisation (in particular ISO technical committee 197 *hydrogen technologies*), the International Electrotechnical Commission (IEC), and the National Fire Protection Association (NFPA).

Connection to the grid

281 The Electricity at Work Regulations 1989 and the ESQC (Electricity Safety, Quality and Continuity Regulations 2002 – currently enforced by DTI) apply to the electrical equipment and connection of distributed generation to the national grid. The Energy Networks Association has produced the following recommendations on grid connection:

- ER G59/1 *Recommendations for the connection of embedded generating plant to the public electricity suppliers distribution systems.*
- ER G83/1 *Recommendations for the connection of small scale embedded generators (up to 16 A per phase) in parallel with public low-voltage distribution networks.*

Conclusion

282 Distributed generation 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 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.

283 In most of these circumstances (including all those subject to the Gas Safety (Installation and Use) Regulations 1998), the workforce is required to have a proven level of competence in relation to gas work. Although the regulations that apply to work on hydrogen installations at commercial premises differ from those applying to LPG and natural gas installations, the overall existing regulatory framework adequately covers all such work. The existing framework of regulatory provisions, codes and standards thus provides a strong basis to ensure that workers and the general public are not exposed to unacceptable risk, though also ensuring that the framework is not unnecessarily burdensome to the deployment of distributed generation and hydrogen economy devices in these new environments.

284 In conclusion, none of these technologies involves risks of a different category or magnitude from those already found in many workplaces and homes, and these risks can be adequately controlled by existing risk control measures. 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, is kept under review.

6 THE GENERATION OF ELECTRICITY BY NUCLEAR POWER STATIONS

285 The Energy Minister asked HSE to report on the health and safety risks associated with a new generation of nuclear power stations, and in the event of nuclear build, the potential role of pre-licensing assessments of candidate designs. This part of our report discusses the risks posed by the operation of a new generation of nuclear power stations and HSE's approach to ensuring that the industry manages them sensibly. The potential role of pre-licensing assessments is introduced here, but is discussed in detail in Annex 2.

286 Not covered in this review are the risks associated with other parts of the nuclear power cycle, such as uranium mining, nuclear fuel enrichment and fabrication, spent fuel reprocessing and radioactive waste disposal. Uranium mining is excluded because there is no such mining in the UK. Fuel enrichment and fabrication do take place in the UK, but on separate sites to nuclear power generation and they present far lower hazards to the public due to the absence of highly radioactive materials. Spent fuel reprocessing is currently undertaken at Sellafield, but this is not a necessary counterpart to new nuclear power generation. The Committee on Radioactive Waste Management (CoRWM), which is due to report shortly, is advising Government separately on options for managing those radioactive wastes for which there are no agreed long-term disposal solutions.

The technology

Overview

287 Coal, oil, gas and nuclear power stations all use a source of heat to boil water and generate high-pressure steam, which is then used to drive turbines to generate electricity. Whereas the coal, oil, and gas power stations generate heat by burning fossil fuels, nuclear power stations use nuclear fission (splitting the atom) as the heat source.

288 In a nuclear power station, the heat is generated in the reactor core, in which a chain reaction is established in fuel rods (or elements) fabricated from special ('fissile') materials. Heat is transferred from the reactor core to the boilers (also known as 'steam generators') by means of a coolant gas or liquid under high pressure. The UK's earliest magnox reactors and later advanced gas-cooled reactors (AGRs) use carbon dioxide as the coolant. Pressurised water reactors (PWR), including the one at Sizewell B, use water in a pressurised primary cooling system to transfer heat from the core, which flows through steam generators to transfer the heat to a secondary cooling system, where high-pressure steam is formed to drive the electrical turbines.

Evolution of the UK nuclear power programme

289 The UK nuclear power programme began with construction of the Calder Hall reactors in 1953. These gas-cooled reactors were designed for both electricity generation and plutonium production, and used natural uranium as the fuel sealed

within cans fabricated from a magnesium/aluminium alloy known as ‘magnox’. Subsequently, a series of commercial nuclear power stations with larger power outputs based upon the same generic design were constructed and these became known as magnox power stations. Altogether, 26 magnox reactors were brought into operation in the UK, and a few were built abroad.

290 The efficiency with which heat can be converted to electrical energy increases with the temperature of the steam sent to the turbines, so the second generation of gas-cooled reactors in the UK, the AGRs, was designed to operate at higher temperatures. This required a change from uranium metal fuel to uranium oxide fuel that has a higher melting temperature, and a change of fuel cladding material from magnox to stainless steel. The pressure of the carbon dioxide coolant was also increased to enhance its heat transfer capabilities, and in all of the commercial AGRs, the reactor cores were contained within massive concrete pressure vessels rather than the steel pressure vessels used for the magnox reactors (except for the final two magnox power stations at Oldbury and Wylfa, which had concrete vessels). The AGRs were a design unique to the UK and altogether, 14 AGRs entered commercial operation.

291 In the 1970s, the Central Electricity Generating Board (CEGB) decided to change to PWR technology, which had by then become the globally dominant nuclear reactor technology. This was a major change from the gas-cooled reactor technology developed and licensed in the UK over two decades. The CEGB envisaged a series of PWRs of the same design, but in the event only one PWR power station was built, at Sizewell B.

Development of nuclear reactor technology

292 The UK’s magnox fleet of reactors are commonly ascribed to the first Generation of reactor designs (Generation I). The AGR designs, along with most of the other commercial designs of reactor built during the last 30 years, are designated Generation II, in terms of their design safety, cost and operational efficiency. This generation of reactors include almost all the pressurised water reactors and boiling water reactors (BWR) currently operating across the world, and includes the original Canadian CANDU heavy water reactor designs. Of about 450 nuclear reactors operating worldwide most are Generation II designs, including Sizewell B, which benefited from some safety improvements compared with earlier Generation II designs. In general, the reliability of these plants has improved over their lifetimes as operational experience has been gained and best practice shared. The ‘backfitting’ of advanced components and systems has also added to the improvements in plant reliability. Operators of many of the plants designed and built in the 1970s, with an anticipated lifetime of 30 years, are now anticipating lifetime extensions of up to 30 years, to give a life of 60 years in total. Along with increases in plant reliability, safety at nuclear plants worldwide has continued to be good, and radiological doses to operators or releases to the environment have generally shown significant decreases as operating experience has increased.

293 Although the Generation II designs have generally proved robust and increasingly reliable, further evolutions of existing designs of PWRs and BWRs, with improved fuel technology and passive safety features, have been developed. Passive safety features are based on natural forces, such as convection or gravity, to ensure a

safe response to an abnormal plant state, rather than pumps, valves or operator actions. These designs are designated Generation III (with the most recent developments designated Generation III+). Research into even more advanced reactor designs (Generation IV) has begun, with the aim of improving safety and proliferation resistance, minimising waste and natural resource use, and decreasing costs of construction and operation. The Generation IV designs are not expected to be available for commercial construction before 2030. For the purposes of this report, therefore, we assume that any proposals for new construction in the UK would use Generation III (or III+) reactor designs.

294 Several designs of Generation III reactors are already operating or under construction and others are under development. In Japan, advanced BWRs designed by GE-Toshiba, have been operating since 1996. At Olkiluoto in Finland, a European pressurised water reactor (EPR) designed by Framatome ANP is currently under construction. A similar design is scheduled to begin construction at Flamanville in France in 2007. In the United States, a number of utilities have expressed interest in Generation III or III+ plants, including the Westinghouse AP1000 PWR. Other advanced designs of reactors are under consideration or construction in Canada, the United States, Japan, Taiwan, India, and Korea. There are currently no advanced designs that have evolved from the UK's gas-cooled AGR type of reactors, but there are designs based on gas cooling and graphite moderation, such as the pebble bed modular reactor being developed in South Africa.

Features of new designs of nuclear power stations

295 Third generation nuclear power stations are generally evolutionary in that they are developments of current designs taking advantage of modern safety philosophy, construction techniques, and benefiting from the significant operational experience gained on the proven Generation II designs. Third generation nuclear power stations will generally have some or all of the following features:

- 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 design 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 and improved accident mitigation,
- lesser impact on the environment;
- higher fuel burn-up to reduce amount of fuel used and the amount of waste.

296 From the safety viewpoint, 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, as they have these improved features, 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.

297 Some of these designs are being examined by overseas nuclear regulators. For example, the Westinghouse AP1000 reactor design has recently been awarded Design Certification (albeit limited in application) by the US nuclear regulators, while the EPR is the design chosen for Finland's fifth nuclear power station and Finnish nuclear regulators have given permission for construction. The significance to the UK of these overseas nuclear regulator decisions is considered further in the discussion on pre-licensing assessments in Annex 2.

Health and safety risks

Ionising radiation

298 The fission of atoms in the nuclear fuel in a reactor core releases heat which is used to create steam to generate electricity. The fission process also produces ionising radiation, which can be harmful to human health. Ionising radiation is emitted by atoms inside a nuclear reactor core. Such radiation has enough energy to remove electrons from atoms or molecules it passes through – this is called 'ionisation'. Ionisation may cause damage to living tissue. Ionising radiation is prevented from escaping from the core by steel and concrete shielding, which absorbs practically all of the radiation. The fission process also means that the material inside or immediately around a reactor core gradually becomes radioactive itself. Moreover, the primary coolant (a gas in AGRs, water in PWRs), which is pumped round a closed circuit through the core and out again to the boilers, also becomes slightly radioactive. This means that in some stations, the whole cooling circuit has to be surrounded by shielding. Although the design of the reactors and the shielding surrounding it will ensure most radioactivity is safely absorbed, some power station workers will receive small doses of radiation during the normal operation of the reactor and particularly when they have to carry out inspection or maintenance, for example, on coolant pipework, circulating pumps and boilers.

299 Waste liquids and gases that accumulate on a station are either routed to a waste treatment plant on the site, where they are further concentrated and the radioactivity retained, or discharged in small amounts to the environment. All disposals of radioactive wastes from nuclear sites are regulated by the Environment Agencies who require that the best practicable means is used to minimise the activity of waste created and to minimise the activity of any gaseous or liquid waste discharged into the environment. The Environment Agencies also require that disposals do not exceed limits that they set, that disposals are monitored and assessed and that the operator carries out environmental monitoring. In setting limits on the activities that can be discharged into the environment the Environment Agencies assess their potential impact so as to ensure that people and the environment are properly protected.

300 In addition to the risks posed to power station workers and the public from routine operation of the plant, releases of radioactive material in accidents have the

potential for causing more significant and widespread radiological harm. The risks of accidents and the control measures put in place to prevent them are discussed later in this section. In addition to the hazards posed by radioactivity, nuclear power stations pose other 'conventional' risks, similar in nature and degree to other generating stations and industrial installations. Most accidents and injuries at nuclear power stations worldwide are the result of conventional health and safety failures. However, for members of the public, it is the risks posed by routine or accidental emission of radiation that cause most concern; for the purposes of this review, therefore, we do not consider non-radiological risks any further.

301 Added to these risks, the public may have concerns about the risks posed by the transport of nuclear fuel to the plant, or the transport of used fuel and radioactive wastes from the plant to Sellafield or elsewhere. The Department for Transport is the regulating authority for such activities, not HSE. This review does not therefore consider the risks posed by radioactive materials transport, or their management.

Risks from normal operation

302 As discussed in paragraphs 312 to 316 below, the Nuclear Site Licence and its Conditions form a legal framework for ensuring nuclear safety. However, there are specific regulations which ensure that operators take measures to restrict the exposure of workers and public to ionising radiation during normal operation. The Ionising Radiations Regulations 1999 (IRR99), which are also enforced by HSE, set exposure limits for workers and public. The maximum allowable annual whole-body dose for workers at a nuclear plant is 20 milliSieverts (mSv); for members of the public exposed to radiation from the plant, the annual dose limit is 1 mSv. However, the application of the ALARP principle results in exposure to much lower levels of radiation. For the UK's most recently built nuclear power station, the Sizewell B PWR, the average operator dose is currently around 0.5 mSv per year, while the annual estimated maximum dose to the most exposed member of the public is less than 0.005 mSv. For comparison, the average annual dose to members of the public from natural background radiation is typically about 2 mSv.

303 While HSE has not had access to any detailed design reports and analysis, from a preliminary examination of current design parameters, it appears likely that the average radiation doses to workers and public from Generation III reactors will be no higher than those from Sizewell B, and hence the risks from normal operation of such plants would continue to be acceptably low.

Risks from accidents

304 While the design, safety assessment and operation of nuclear power stations are conducted with the objective of never having accidents that lead to uncontrolled releases of radiation, such accidents cannot be ruled out entirely. Within the UK, our regulatory framework requires that the risk of accidents occurring must be ALARP, and, for added protection, accident mitigation measures must also ensure that any resultant radiation exposure is ALARP.

305 In nuclear power stations, the risk of accidental release of radioactivity is reduced through a series of barriers based on a comprehensive safety analysis that

examines all the faults that can happen on the reactor, and all the internal and external hazards (fire, flood, earthquake etc) that might occur. This should demonstrate that the reactor design is sufficiently rugged to withstand these faults and hazards and that the plant is operated with large margins of safety. It is always possible, however, that some of the plant may fail to operate correctly. To protect against this, an approach of defence-in-depth is adopted. This basically means that if one part of the plant fails, then another part is available to fulfil the same safety duty. To maximise the protection, different back-up systems and other safety features can be provided. This multi-barrier protection concept can be repeated until the risk of an accident is acceptably low.

306 In modern reactor design, these concepts are well understood and we would therefore expect any new reactor designs to be able to demonstrate an acceptably low level of risk. If this was not the case, NII would not grant a site licence that allowed the reactor design to be built.

307 In the past, some reactor designs have not had sufficient defence-in-depth and they were not scrutinised in a sufficiently robust manner so as to reveal the shortcomings and allow additional protection to be provided. As a result, accidents have occurred. The most notable are:

- UK, 1957: the Windscale fire. The graphite core of a very early reactor design caught fire, leading to melting of fuel and release of significant amounts of radioactivity. This highlighted the need for additional barriers to prevent radioactive release. Follow-up actions included improvements to the UK regulatory framework and establishment of an independent nuclear inspectorate – what is now NII.
- USA, 1979: Three Mile Island PWR No. 2. A cooling malfunction caused a large part of the core to melt. The containment barriers were effective. Some radioactive gas was released a couple of days after the accident, but not enough to cause any dose above background levels to local residents. Investigation found that the operators had been unable to diagnose or respond properly to the developing accident. Deficient control room instrumentation and inadequate emergency response training proved to be root causes of the accident. Improvements made as a result included to operator training, emergency planning, and better use of probabilistic safety assessments.
- Ukraine, 1986: Chernobyl. An explosion occurred in one of the four reactors and a substantial portion of the fission products in the reactor core and some of the fuel were released directly to the environment, causing widespread contamination. The event was caused by a combination of human and design issues. Lessons learned led to safety improvements being implemented on many East-European reactors and, for the west, an underlining of the importance of defence-in-depth and a safe operating culture.

308 In summary, these previous events have led to safety improvements being adopted and these improvements are further developed within the third generation reactor designs.

Regulatory strategy and standards

309 There is a comprehensive and well-tested framework of legislation governing the health and safety aspects of the nuclear industry. As explained in chapter 1, there is a general framework of health and safety at work law that all operators of nuclear plants will need to comply with. This framework of legislation is backed up by exacting assessment, licensing, inspection and enforcement methodologies centred on the licensing of nuclear sites. Licensing is a well established and documented process and includes, for significant new licences, arrangements for stakeholder consultation.

310 Licensing is based on the Nuclear Installations Act 1965 (as amended). Originally enacted in 1959, the Act sets out a requirement that, in order to install or operate such installations, the operator must have a licence granted by HSE. Those parts of the Act relating to licensing subsequently became relevant statutory provisions of the HSW Act, which set up HSE. HSE delegates its power to grant nuclear licences to HM Chief Inspector of Nuclear Installations, who is a Director of HSE.

311 As explained in chapter 1, in determining whether any additional measures are necessary to reduce the risk posed by their activities, and achieve compliance with the HSW Act, employers need to consider the cost of those measures, whether in money, time, trouble or effort, and the risk which would be averted by their implementation. Such measures should be implemented unless the cost is grossly disproportionate to the risk that would be averted. In short, risks must be reduced to a level which is ALARP. This concept and the way in which nuclear risks are regulated is explained in HSE's publication *The tolerability of risks from nuclear power stations*, and further promulgated in the HSE publication *Reducing risks, protecting people*. The basic philosophy is that risk must not be unacceptable and the licensee must demonstrate that they have done everything practicable to reduce the risk to the ALARP level.

The nuclear site licence

312 Licensing applies throughout the lifetime of a nuclear power station from design, siting, construction, commissioning, operation, and modification to eventual completion of decommissioning.

313 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. HSE also has power to vary or revoke Conditions attached to a licence, so providing scope for the licence to be tailored to specific circumstances and the different phases of a station's life. In this way, the licence becomes a regulatory tool which, through the Conditions attached to it, allows HSE to define those areas where the licensee should pay particular attention to nuclear safety matters. The power to attach Conditions is delegated to HM Chief Inspector of Nuclear Installations.

314 A standard set of non-prescriptive Conditions was developed in the late 1980s, which has facilitated the application of consistent regulatory safety requirements and a variety of licensees and installations. These Conditions cover safety-related functions such as:

- 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.

315 These Conditions, in the main, require the licensee to make and implement adequate arrangements to address the particular issues identified (which include some public duties of the licensee – eg relating to emergency arrangements). Although the Conditions are essentially the same for all licences, the arrangements made by individual licensees to comply with them will be different. In addition, the arrangements may change as the plant progresses through its life from initial design to final decommissioning. Therefore each licensee can develop arrangements that best suit its business while demonstrating that safety is being properly managed.

316 While the Conditions provide the basis for regulation by NII, they do not relieve the licensee of the responsibility for safety. The arrangements that a licensee develops to meet the requirements of the licence Conditions constitute elements of safety and radioactive waste management systems. NII reviews the licensee’s arrangements to see they are clear and unambiguous and address the main safety issues adequately. NII looks for consistency between the assumptions and commitments made in the safety case and the safety management system.

Inspection and enforcement

317 It is NII’s role, in relation to nuclear and radiological safety, to see that appropriate standards are developed, achieved and maintained by the licensee and to ensure that the necessary safety precautions are taken. This role is carried out by:

- ensuring that licensees establish, manage and maintain safety requirements for the protection of employees and members of the public;
- assessing the safety of proposed and existing sites and nuclear plant designs;
- inspecting sites for compliance with these requirements at all stages from construction, through operation, to eventual decommissioning
- taking measures to secure compliance.

318 NII monitors and regulates the nuclear and radiological safety aspects of a nuclear installation by means of its powers under the HSW Act and through the licensing regime. Non-nuclear health and safety aspects are also the concern of inspectors from HSE’s Field Operations Division. Close liaison is maintained between HSE’s nuclear inspectors and those of other HSE Divisions in dealing with

nuclear installations. Similarly, NII liaises closely with its colleagues in the Environment Agencies and the Office for Civil Nuclear Security.

319 NII makes use of a number of controls derived from the Licence Conditions, which include giving Consents, Approvals or Directions. These allow NII, for example, to permission certain operations, such as the start-up of a reactor after a major maintenance period. Additionally, where required, NII uses its enforcement powers under the HSW Act to issue Prohibition and Improvement Notices and to prosecute for breaches of that Act or the relevant statutory provisions. Breaches of Licence Conditions or HSW Act Notices are criminal offences.

The safety case

320 In the course of its nuclear regulatory work, NII scrutinises the activities of a licensee both at a site and through assessment of the licensee's written submissions. These submissions, together with supporting reports, are generally referred to as the 'safety case'.

321 It is the responsibility of the licensee to prepare, maintain and update a safety case to demonstrate the safety of its plant. The licensee should use the safety case to produce schedules of items for its own inspection and maintenance, in addition to the specification of working instructions, equipment analysis requirements, plant operating rules and limits, procedural specifications and a training agenda.

322 NII examines the safety case to satisfy itself that the claims of the licensee are justified or demonstrated. For site inspections, NII uses the safety case to help to prepare inspections and to determine parameters and values against which to judge the plant and its operation.

Assessment methodology

323 It is the responsibility of the licensee (or licence applicant) to provide a comprehensive demonstration in its safety case that safety will be properly controlled through all stages of the plant's life. It is important to note that we take a holistic whole-life approach. We therefore expect the safety submission to cover not only the design, but also aspects such as construction, maintenance, operation, radioactive waste and decommissioning. The format for safety cases is not prescribed; however, in 1992, HSE published the current version of Safety Assessment Principles (SAPs) against which it assesses the adequacy of licensees' safety cases. These are now being revised (see paragraphs 329 to 331).

324 The purpose of assessment by NII is to confirm the evidence in the safety case that the installation is as safe as is reasonably practicable. This is achieved by probing carefully selected parts or samples from the safety case. It may involve reviewing underlying argument and analysis, or monitoring manufacturing activities, inspection and testing or discussion for clarification, requests for further justification or experimental work.

325 The majority of the current SAPs are engineering (or 'deterministic') principles. In creating a design, there are many choices to be made; each choice

involves to a greater or lesser extent the use of judgment in technical, scientific or commercial issues. Not all of these judgments are concerned directly with safety, but most will influence its achievement. The engineering SAPs provide NII assessors with guidance on what to look for when judging the ALARP arguments in a design safety case. They represent NII's view of good nuclear engineering practice and set out the provisions that in NII's view would lead to an acceptably safe plant.

326 NII will expect a licensee's safety case to make use of probabilistic safety analysis (PSA) as part of a methodical accident analysis process. It can also provide numerical estimates of the risk from the plant for comparison with the targets set out in the SAPs. PSA provides a comprehensive logical analysis of the potential for things to go wrong on the plant and the roles played by the safety provision. PSA enables weaknesses in the design to be identified, anticipated and remedied at an early stage, and provides evidence that confirms the 'balance' of the plant. A balanced plant is such that no particular class of accident or feature of the plant makes a disproportionate contribution to the overall risk. PSA acts as a cross-check on the level of safety achieved, so that the PSA and engineering SAPs are complementary.

Independent examination of NII methodologies

327 NII's methodologies have been subject to searching independent scrutiny. The SAPs published in 1992 were the subject of consultation within the industry, and for the development of HSE's *Tolerability of risk* document, a formal public consultation was carried out. Many other NII documents have been published and licensees and the public may make representation on NII's methods. The Nuclear Safety Advisory Committee (NuSAC) advises the Health and Safety Commission (HSC) independently on specific nuclear safety issues, including for example on nuclear safety issues arising from the energy review, and the Committee often seeks evidence from NII.

328 A thorough, searching and formal examination of NII's methodologies took place in the Sizewell B and Hinkley Point C public inquiries, which resulted in an endorsement of NII's methods and expertise. In addition, as discussed further in Annex 2, NII's capabilities and methods of working were recently reviewed by a team from the International Atomic Energy Agency (IAEA). The IAEA team identified a number of good practices within NII and these will be publicised worldwide for the benefit of other countries. This review also identified a number of suggestions and recommendations for improvement which are being addressed (for further detail see Annex 2 paragraph 44). The good practices included:

- a mature and transparent regulatory system and an advanced review process;
- highly trained, expert and experienced staff;
- a flexible regulatory regime that sets clear expectations for the licensees and permits NII to make decisions on well-justified technical grounds.

Review of SAPs

329 Although the current version of the SAPs has proved to be robust, two years ago, NII began a review process to:

- build on learning from the application of the SAPs;
- take account of the changing focus of the UK nuclear industry, which is now much more involved in decommissioning and radioactive waste clean up; and
- reflect international moves towards harmonisation of safety standards.

330 The first two of these objectives have been largely met by NII's development and use of an extensive set of Technical Assessment Guides (TAGs) to support the existing SAPs. Some of these TAGs have been available publicly for several years so have a similar wide appreciation as the SAPs. The third objective has been addressed by undertaking a benchmarking exercise with the latest suite of International Atomic Energy Agency (IAEA) Safety Standards.

331 Consideration of these factors led NII to identify a clear need to revise substantially the format of SAPs and add to their content. Key stakeholders were engaged during the development of the proposed revision and public views have been elicited over a period that ended on 31 May 2006. While it is too early to give a detailed summary of the results of this process, early review indicates general support for NII's proposals. The current plan is to publish the revised SAPs by the end of this year.

International obligations

332 Through membership of bodies such as the European Union and the United Nations, the UK is bound by a number of international treaties relating to atomic energy. In general terms, these set down international safety standards and expectations, some of which relate to reactor siting, design, construction and operation (for example, the Convention on Nuclear Safety, and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management). NII seek, to ensure these obligations are met and this is achieved through the UK legal framework and by the principles set out in the SAPs. We would expect these to be met for any new nuclear build proposals.

Licensing of new nuclear power stations

333 The licensing process that could be applied to any new nuclear power stations is discussed in Annex 2. However, whatever procedure is applied, the UK nuclear regulatory framework will apply and this means that there will be certain requirements that must be met. Construction will not be allowed to start 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 will require an acceptable safety submission.

Safety submissions for new nuclear power stations

334 General guidance on the purpose, scope and content of safety cases can be found on the HSE website at www.hse.gov/foi/internalops/nsd/tech_asst_guides/TAST051.pdf. The licence applicant usually holds discussions with NII during the development of the safety case, before its formal submission. Submission to NII could be in stages or in one complete package.

335 For Sizewell B, the licensing assessment topics were divided into 15 areas of interest. These are listed in the table below. Regardless of design and licensing procedure details, it is highly likely that any Generation III nuclear plant safety assessment would cover broadly the same areas.

TABLE. Safety assessment topics

	Safety assessment topic	Example of contents
1	Topics of general application	Design criteria, human factors, quality assurance, fire protection
2	Siting, site and surroundings	Demography, geology, hydrology, site layout, external hazards
3	Nuclear design	Pressure vessel, reactor components, irradiation effects, shutdown margin, stability
4	Fuel element behaviour and core thermal hydraulics	Thermal and hydraulic design, fuel limiting criteria, fuel behaviour in normal and fault conditions
5	Civil works and structures	Reactor foundations, containment structure
6	Reactor pressure vessel integrity	Design, manufacture, fracture analysis, inspection, operation
7	Pressure circuit integrity	Coolant loop piping, coolant pumps, pressuriser, steam generators, reactor internals, valves
8	Protection systems and safety-related instrumentation	Design basis, fault situations, initiation system, interlocks, reactor trip system, pressure protection, heat removal system
9	Plant chemistry and corrosion	Activated corrosion products, steam generator secondary side, post-accident chemistry
10	Radioactive waste management	Assessment basis, safety case
11	Radiological protection	Dose control during operation, demonstration of ALARP
12	Fuel handling and storage	Storage pond integrity, failed fuel handling
13	Safety analysis	Fault schedule, fault analysis, transient analysis, fault probabilities and consequences
14	Decommissioning	Arrangements for safe decommissioning
15	Research and development (R&D)	Ongoing R&D programmes to support the safety case

336 NII does not set out to examine all parts of a safety case in depth. Different aspects are examined at different levels of detail. To help assess the applicant's submissions, NII may seek independent data and advice from external sources, such as consultants or university research departments. In all cases, the licensee will need to demonstrate to the satisfaction of NII that it has an adequate safety case for the activities which it proposes to undertake, and that it can implement suitable arrangements to comply with all of the conditions attached to the site licence.

337 Under the law, the responsibility for ensuring safety lies always with the licensee. HSE's regulatory assessments, while adding reassurance that safety has been adequately considered in the licensee's safety case and operational procedures, do not relieve the licensee of its absolute legal duties to ensure that all risks are controlled so far as is reasonably practicable.

Capability of potential licensees

338 The responsibility for the safety of a nuclear installation is placed on the licensee by the NIA65. Before granting a licence NII must be satisfied that the applicant has in place an adequate management structure, and the capability and resources to discharge the obligations of a site licensee.

339 NII expects any prospective licensee to develop and submit a safety management prospectus demonstrating its commitment to health and safety. The safety management prospectus is that part of a licensee's safety case which deals with safety management issues. The prospectus should provide a clear statement about the company, its structure and how it proposes to operate. HSE would expect the safety management prospectus to include the following items:

- a corporate safety policy statement;
- overview of the applicant's organisation, management structure and resources;
- relationship with associated corporate bodies, such as its parent companies;
- lines of authority demonstrating adequate control of activities;
- definition and documentation of staff duties and staff training arrangements;
- proposals for safety case production (including modifications);
- proposals for the use of contractors.

340 As the licensee must continue to maintain licensing requirements throughout the duration of the licence, they must keep the safety management prospectus under review and revise it when significant changes occur.

341 The main safeguards for the public from the hazards associated with the operation of a nuclear installation are the high standards of design, construction, commissioning and operation. Although a major accident is extremely unlikely it is prudent to consider the number of people who may be exposed to its consequences.

342 For new reactor sites, HSE will expect the licensee to submit details of present and predicted population around the site out to 30 km. Information on nearby schools,

industry, hospitals, institutions and other places where people may congregate will be sought. HSE will assess this information against relevant criteria, including the Government's siting policy, and will expect to see an allowance for natural population growth around the site. Siting is discussed further in Annex 2.

The role of pre-licensing assessments

343 The Energy Minister particularly asked HSE to report on the potential role of pre-licensing assessments of candidate designs.

344 Pre-licensing is nothing new to the UK. At the request of the Government, NII undertook a pre-licensing assessment of the generic safety aspects of pressurised water reactors in the 1970s – well in advance of the subsequent application for the construction of Sizewell B in 1981. Likewise, in advising the Government on its *Nuclear Review* in 1994, NII undertook some preliminary pre-licensing assessments of a variety of then current reactor designs.

345 However, in response to the Minister's request, HSE has undertaken a review of its possible approach to any new requests that it may receive to undertake pre-licensing assessments. These could be from private sector organisations with an interest in building and operating Generation III (or III+) designs in the UK. In undertaking this review, HSE has engaged in an open and transparent way with a range of stakeholders. As a result of that interaction, combined with our own further analysis and the expert advice from the IAEA regulatory review team, we have concluded that in future, new nuclear power plants could be subject to a more methodical, better defined, multi-stage assessment and licensing process. This would have two phases, Design Acceptance and Site Licensing. These proposals are described in more detail in Annex 2.

Conclusion

346 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 very recently has been subject to peer review by international experts.

347 Construction of any new nuclear power station will not be allowed to start until a Nuclear Site Licence has been granted. NII will not issue a Licence unless it is content with the proposed reactor design, the site location, and the capacity of the licensee's organisation.

348 To be satisfied with the design, NII will require a detailed and acceptable safety submission and be satisfied that the risks are ALARP.

349 NII has satisfactorily regulated nuclear reactors of 'first' and 'second' generation designs. We anticipate that any new reactors proposed will be of the current 'third' generation and they will therefore be an evolutionary design making use of proven technology and operating experience, and will benefit from modern safety analysis techniques and philosophies. We would therefore expect that suitable

licence applicants could demonstrate appropriate levels of safety and with risks no greater than those of existing reactors. However, for NII to play fully its part in future regulatory arrangements it will need to be appropriately resourced.

7 CLEANER COAL TECHNOLOGIES

The technology

350 The world's most abundant fossil fuel is coal. Its widely distributed reserves are considered to be sufficient to satisfy the global energy demand for several centuries. Almost 40% of the world's electricity is currently generated using coal and it is expected to continue to be the major fuel source for the growing demand for electricity.

351 Coal is, however, not a perfect fuel. It has a higher proportion of carbon than other fossil fuels and consequently, when burned, produces comparatively more carbon dioxide. In addition, most coals contain significant amounts of sulphur, nitrogen and incombustible material. These impurities and the combustion process produce sulphur and nitrogen oxides (SO_x and NO_x) and dust. When flue gases containing the oxides of sulphur and nitrogen are released into the atmosphere, they combine with water vapour and produce environmentally damaging acid rain.

352 Cleaner coal technologies (CCTs) are those that enable coal to be used in an environmentally acceptable and economically viable manner. They are most commonly associated with the use of coal for electricity generation. They lessen the environmental impact of coal-based power generation by reducing the amount of carbon dioxide, dust and sulphur/nitrogen oxides released into the atmosphere. Plants using CCTs are able to produce less carbon dioxide when generating a unit of electricity than is currently released by UK power stations. Furthermore, these technologies are being developed with their future suitability for integration with carbon capture and storage (CCS) schemes in mind, offering the potential for fossil-fuel power production with very low carbon emissions. The scope of this report extends beyond advanced surface-based electricity generation technologies to include new approaches for extracting energy from underground coal reserves.

353 Coal can be used to generate electricity through direct combustion or by processes involving gasification. Combustion is the traditional method, being first commercialised at the start of the twentieth century. Gasification specifically for power generation is a more recent development. It can be carried out on a separate site, with the gas being piped to a power plant, or be integrated with the generating station in a single integrated gasification combined cycle (IGCC) plant.

354 All current UK coal-fired power stations are combustion plants. At present, there are no coal gasification plants. Both types of technology will, however, be considered in looking in more detail at the processes available for generating electricity from coal.

Combustion of coal

355 The combustion technologies most widely used around the world may be grouped into two general categories – pulverised fuel (pf) and fluidised bed.

Pulverised fuel (pf)

356 This is by far the most widespread technology used in coal-fired power plants. All the major UK generating stations were designed over thirty years ago and use the pulverised fuel (pf) method. In its simplest form, this may be considered the baseline technology against which the advances associated with CCTs can be related.

357 In the pf process, coal that has been ground to a very fine powder is blown into the combustion chamber of the power station boiler. The coal particles burn very quickly and heat up water in tubes surrounding the combustion chamber and produce steam. This high pressure, high temperature steam is fed into a steam turbine that spins an alternator and generates electricity. The existing UK pulverised fuel plants operate with steam at relatively low (190 bars) pressures and temperatures (570 °C) and return average thermal efficiencies of around 38%. Boilers such as these, that produce steam at pressures less than 221 bar, are said to be using subcritical steam cycles.

358 In addition to its relatively modest efficiency, the pulverised fuel process has very high (1500 °C) combustion temperatures that produce flue gases with high levels of nitrogen oxides. Furthermore, during combustion all the sulphur present in the coal feed is converted to SO_x, which leave in the flue gases. To prevent these gases being discharged into the atmosphere, UK pulverised fuel coal plants are fitted with scrubbing systems to remove these polluting gases. After scrubbing, the flue gases pass through bag filters or electrostatic precipitators to remove dust.

Fluidised bed combustion

359 Boilers of this type are fed a more coarsely ground fuel. The particles of burning coal are kept suspended inside the combustion chamber by an upward flow of hot air; the floating mass of burning coal particles resembles a boiling, red-hot liquid. Fluidised bed plants produce much lower levels of sulphur and nitrogen oxides in their combustion gases than pulverised fuel stations. The lower combustion temperature (900 °C) leads to NO_x levels typically one fifth of those from pf plant, while powdered limestone can be added with the fuel to capture SO_x as they are formed. Although there are currently no UK power stations using fluidised bed combustion, the technology is mature with many plants of this type operating around the world.

Cleaner combustion technologies

360 Both the pf and fluidised bed combustion technologies have been further developed to increase their environmental acceptability. The three areas of concern identified earlier – carbon dioxide, sulphur and nitrogen oxides and dust – have all been addressed.

361 Against a backdrop of concerns regarding climate change, the amount of carbon dioxide produced for each unit of electricity generated is the central concern of the development of cleaner coal technologies. The more thermally efficient a power

station is, the lower its emissions of CO₂ will be for a given output of electricity. Significant advances have been made in the last 25 years.

362 In general, the higher the temperature and pressure of the steam generated in the power station's boiler, the greater its potential efficiency. Supercritical pulverised coal plant are in routine operation in many countries, regularly achieving efficiencies of 43–45% those currently under construction are expected to raise this to 47%. Research work, supported by the EU, is investigating the feasibility of steam pressures and temperatures of over 300 bar and 700 °C respectively, potentially returning efficiencies of over 50%.

363 The advances in steam plant efficiency discussed above with regard to pf plant are generally equally applicable to fluidised bed technology. This technology, however, is capable of achieving very low levels of sulphur and nitrogen oxide levels without flue gas scrubbing. In pf plants, improved burner designs etc have been developed and large (60%) reductions in the amount of NO_x formed during combustion have been achieved.

364 A lot of work is being done to ensure that the design of new coal-burning plant is consistent with future integration with carbon capture technology. This will maximise the opportunities for building coal-fuelled power stations with near-zero CO₂ emissions in the medium future.

Gasification

365 Gasification is a technology that has been used for almost a century. It differs from traditional combustion in that the amount of oxygen allowed into the process is tightly controlled so that only a small amount of the solid fuel (usually coal, coke, biomass, waste etc) is allowed to burn normally. The majority of the fuel is chemically broken down to produce a mixture of hydrogen, carbon monoxide and other gaseous products called syngas. It is following this stage in the process that great potential exists for future projects to remove carbon dioxide. The syngas can be further processed to hydrogen, which goes forward for combustion or for use in fuel cell applications, and a concentrated CO₂ stream that is suitable for capture.

Integrated gasification combined cycle (IGCC)

366 In current integrated gasification combined cycle (IGCC) plant, the syngas is used directly for power generation. The dust and the sulphur and nitrogen pollutants are removed, and the syngas is used to fuel a gas turbine. The rotating turbine drives the generating set producing electricity. The hot exhaust gases leaving the turbine are then used to generate steam, which is used to make more electricity.

367 Three general types of gasifiers are used for IGCC power generation:

- entrained bed;
- fixed bed;
- fluidised bed.

368 Fluidised bed gasifiers are relatively new, whereas the chemical industry has used entrained and fixed-bed gasifiers for many years. Gasifiers may use air or oxygen-enriched air to breakdown the fuel and operation under pressure (20–40 bar) is generally considered necessary for IGCC applications.

369 IGCC is a very efficient process for generating electricity, with thermal efficiencies of around 45% and projections that this may rise to over 50% in the near future. The extensive cleaning the syngas receives before combustion, and the use of highly developed, low NO_x gas turbines mean that emissions of dust and the oxides of sulphur and nitrogen from IGCC plants are very low.

370 Although there are a number of large coal-fuelled IGCC power generating plants operating in several countries, the deployment of the technology has been relatively slow due to competition from natural gas combined cycle plants.

Underground coal gasification (UCG)

371 This is a process for obtaining energy from coal without the need for underground mining. The concept is not new – in the 1930s it was operated on an industrial scale in Russia, and more recently a series of trials have been carried out in Europe, Australia, North America and China. It has been proposed for coal reserves that are too deep or hazardous to be economically exploited by conventional mining, UK coal resources suitable for deep-seam UCG on land have been estimated at 17 billion tonnes.

372 The process involves carrying out gasification deep underground by passing a stream of oxygen and water down a well into a preheated coal seam. The gasification reaction takes place under pressure in the seam and the syngas produced is drawn out through a second well. In general, the deeper the seam, the more suitable it is to this technique. The syngas produced during recent trials was found to be of similar quality to that produced in conventional gasifiers.

373 Although there are currently no UCG installations operating on a commercial basis, recent successful trials in Spain and Australia have demonstrated the feasibility of using the technique in coal seams at depths of at least 550 m.

Coal bed methane extraction

374 Virtually all coal seams contain some trapped methane; the amount varies with the depth of the seam and the type of coal. This methane starts to be released when the structure of the seam is disturbed and has led to many fatal underground explosions during mining operations.

375 The methane trapped within virgin coal seams is called coal bed methane (CBM) and can be extracted by drilling wells down from the surface into the seam. In America there are over 6000 wells recovering coal bed methane. In general the quality of the gas collected is comparable to the natural gas recovered from petroleum reservoirs and is frequently mixed with it in the transmission system.

376 A lot of research is currently taking place to investigate possible synergies between CBM recovery and the storage of captured carbon dioxide (CO₂) in unmineable coal seams. Injection of CO₂ has been shown to significantly increase the amount of gas recovered from the coal seam by displacing methane adsorbed onto the surface of the coal. This process is called enhanced coal bed methane recovery (ECBM).

Operational issues

Combustion technologies

377 In general, the combustion and pollution abatement techniques are well established and few major operation issues are encountered. Thermal cracking of refractory linings, particularly on fluidised bed plant, continues to be a reliability concern. Recent designs are using thinner linings in an attempt to solve this problem by minimising thermal expansion. The first supercritical fluidised bed plant, currently being built in Poland, should provide valuable knowledge on this and many other material-suitability issues.

378 Taking advantage of developments in materials and fabrication techniques, pulverised fuel plants employing supercritical steam systems have been successfully installed in many countries, including Denmark, Germany and Japan. All these installations are reported to be operating well with satisfactory performance and reliability. As a result, supercritical plants are frequently the preferred option for new build.

Gasification technologies

379 Although there are several hundred gasification plants worldwide, there are less than ten commercial-scale IGCC plants using coal. This is largely due to their relatively high capital cost, perceived complexity and concerns regarding plant reliability.

380 Unreliable coal feed systems and poor carbon conversions have been matters of concern at some installations. While short refractory life, corrosion and plugging of the syngas coolers have been widespread. The performance and reliability of the particulate removal system has also been unsatisfactory at several sites. Eventually, however, most of the serious operational issues on coal-fuelled IGCC generating plants appear to have been brought under control and their environmental performance is reported to be very good.

381 Underground coal gasification (UCG) feasibility studies are underway in Asia (Australia, Japan and India) and Europe (UK, Slovenia, Poland and Portugal). While in North America, there is considerable interest in its potential as a fuel source for the hydrogen economy.

382 While significant ongoing advances in directional drilling in coal seams are progressively reducing some of the operational obstacles to UCG, there are still many technical issues needing resolution. These include maintaining and controlling the

gasification reaction over long runs within seams and monitoring the environmental impact of the process.

Coal bed methane extraction operations

383 Several wells have been drilled in the UK, but many have encountered problems with drilling techniques. Interest continues, however, as oil industry expertise in directional drilling becomes available.

384 Carbon dioxide injection (ECBM) has been successfully employed in New Mexico, where it has been found to liberate significantly more methane than simple drilling into the seam.

Health and safety risks

Health hazards

385 Coal combustion and gasification processes involve substances and materials that can present a serious hazard to human health. These include coal, materials such as ceramic or refractory fibres used for thermal insulation, scrubbing chemicals, hydrazine in boiler feed water and the by-product gases, dusts and tars.

386 All the cleaner coal technologies nonetheless produce significant quantities of dust. This respirable dust can contain silica, nickel, vanadium, mercury and polyaromatic hydrocarbons (PAHs) and presents a significant occupation health hazard. Exposure to coal dust is known to cause several serious health problems, including pneumoconiosis, progressive massive fibrosis and chronic obstructive pulmonary disease.

387 Hydrazine is a carcinogen and is used in power stations as an additive to boiler feed water to prevent pipework corrosion. The addition of hydrazine to boiler systems was done manually using a lance and drum pump until recently. However, in the past few years there has been a move to automated hydrazine dosing and semi-enclosed systems.

388 The flue gases from the combustion of coal contain high concentrations of carbon dioxide. This gas has been recognised as a workplace hazard for over a century and its effects on people are well understood. Carbon dioxide is significantly heavier than air and many fatalities from asphyxiation have resulted from entry into boilers, tanks, sumps or cellars where the gas has accumulated. When inhaled, CO₂ produces symptoms that depend upon its concentration and the length of exposure. These range from headaches and mild narcotic effects, through intoxication, to unconsciousness and finally asphyxiation. It is particularly important that the hazard from carbon dioxide is recognised when assessing the risks associated with entry into confined spaces during maintenance etc.

389 The primary product of gasification, syngas, is a mixture of hydrogen and carbon monoxide. Carbon monoxide is highly toxic by inhalation as well as being flammable. The normal oxygen-carrying function of the blood is severely impaired by

carbon monoxide, which is absorbed by haemoglobin in preference to oxygen. As a result, quite low concentrations of carbon monoxide will readily cause incapacity, unconsciousness and death.

390 In addition to the primary output of gasification, syngas, the process also produces a wide variety of by-products, many in the form of liquids and tars. These materials have been shown to contain a number of substances (such as phenols, amines and aromatic hydrocarbons) that present serious health hazards. Their presence is not unexpected, since gasification of coal was once the principal production route for these materials. Benzene and some related compounds (for example, PAHs) found in gasification by-products are recognised carcinogens, others (such as phenol and methanol) are toxic.

391 The hazardous substances present in cleaner coal installations should, whenever reasonably practicable, be used or produced in enclosed systems with exposure minimised through effective process design so that the risk from inhalation is well controlled. Respiratory protection will be required, however, for activities such as removal of refractory fibre and other unavoidable short-term activities that may result in high exposures, such as changing filters and maintenance work. Similarly, it should be practicable to minimise skin contamination by ensuring contact is very infrequent through effective process design, and training in the use of appropriate gloves and overalls when manual intervention is unavoidable.

392 Effectively implementing risk control measures in a practicable manner in respect of gasification equipment presents a significant challenge. Plant of this type requires considerable maintenance. Much of this work will be clearing blockages and accumulations of hazardous tars, fused deposits and dust, and will involve hard physical work in hazardous, hostile environments. There is, however, considerable relevant experience within the process industry regarding how these tasks may be carried out using safe systems of work.

393 The routine working environment in many parts of large power plants is frequently noisy and sometimes very hot. These hazards can produce severe long-term (noise-induced hearing loss) or short-term (heat stress) ill-health effects if the hazards are not adequately controlled.

Machinery hazards

394 In general, the dangers from the machinery used in the production of electricity from coal are obvious, well-recognised and understood. High temperatures, high pressures, high voltages and moving machinery are the major hazards that are presented by plant items. While these hazards are always present when the plant is operating, their potential for causing a hazardous event is particularly high during those periods when the plant is not running steadily, such as starting up, shutting down or during maintenance.

Process safety hazards

395 There are hazards associated with the gasification process that require control. It is foreseeable that some of the gasifiers associated with IGCC installations will

operate under pressure and use oxygen-enriched air. The escape of oxygen into the vicinity of the gasifiers or leakage into syngas are significant hazards resulting from the combination of these two techniques. Localised oxygen leaks greatly increase the likelihood of under-lagging fires, while contamination of syngas with oxygen has resulted in explosions in downstream plant.

396 Syngas is a mixture of carbon monoxide and hydrogen, both of which are flammable gases that will readily form explosive mixtures with air or oxygen. In addition, the viscosity of hydrogen is so low that it is extremely difficult to prevent it from leaking out of equipment and catching fire or forming a potentially explosive cloud. It may also cause the embrittlement of some commonly used metals.

397 Corrosion is a significant potential hazard for CCT plants. Combustion plants operating supercritical steam systems will need to recognise that the rate and location of corrosion in these new systems will not be as readily predictable as in traditional subcritical plants. In gasification plants, corrosion and erosion are well known problems that will need effective management.

398 A fundamental requirement for improving the efficiency with which energy is extracted from coal involves using much higher steam pressures and temperatures. There is very limited experience of operating supercritical steam systems within the UK power generation sector, so the implications of this change in technology need to be determined and addressed. The change from subcritical to supercritical conditions is not simply an increase in pressure and temperature. The properties of supercritical fluids are markedly different from those previously used.

399 The hazards associated with the extraction of coal bed methane are associated primarily with the flammability of methane. This hazard is well known within both the coal and oil/gas sectors and effective risk control measures have been developed.

The regulatory framework

400 We have already described in this report the general regulatory framework (see chapter 1) and more specific controls on major hazards such as the COMAH Regulations and the pipeline and offshore regulatory framework (see in particular chapter 2). The following additional regulatory controls (paragraphs 401 to 409) should be noted.

Pressure Equipment Regulations 1999

401 These Regulations implement the EU Pressure Equipment Directive and aim to ensure that only pressure equipment, including steam plant and pressured gasifiers, that has been appropriately designed and manufactured is put on to the market.

Pressure Systems Safety Regulations 2000

402 These Regulations cover the design, installation and operation of pressure systems. They require users and owners of pressure systems to demonstrate that they know the safe operating limits of their systems and that they are safe under these

conditions. They also need to ensure that a suitable written scheme of examination is in place and that the system is actually examined in accordance with the written scheme.

403 In terms of the overall adequacy of this regulatory structure, the cleaner coal technologies reviewed are developments of previously regulated activities and should not present any significant challenges to the existing health and safety regulatory framework.

Controlling occupational hygiene risks

404 All the cleaner coal technologies considered in this report are developments or refinements of mature processes. While the thermal efficiency of the processes has been improved, the significant occupational health issues have changed very little over the last 20 years. The hazardous substances and physical hazards likely to be present in clean coal projects are generally those that have been recognised by duty holders and regulators for some considerable time. The risks from these hazards have been assessed and effectively controlled by a well-developed framework of standards, codes of practice and guidance.

405 Consequently, the existing regulatory framework is considered suitable and appropriate to control the occupational health risks arising from the foreseeable exposures to those substances likely to be encountered in CCT projects. Similarly, the other frequently encountered occupational health hazards (eg noise, stress etc) will also be effectively controlled through the existing legislative provisions.

Controlling process safety risks

406 With the possible exception of underground coal gasification, the cleaner coal technologies discussed above present no novel process safety challenges. The significant process safety hazards associated with CCTs, such as explosive dusts/gases and hazardous substances, and the appropriate risk management techniques are well known and understood by duty holders and regulators. The challenge for duty holders and regulators will be to identify appropriate and practicable risk control measures and ensure that they are consistently applied in challenging physical and commercial environments.

407 Underground coal gasification, the most novel of the technologies, represents the application of an established technology in a novel environment. Although past experience from traditional gasification operations and recent trials will provide a basis for beginning to understand the process, UCG is an undertaking that is radically different to carrying out gasification in a purpose-designed plant. The ability to control operation parameters or intervene during UCG is greatly reduced. Consequently, much more information will be required before the risks associated with UCG can be suitably assessed and an appropriate risk control regime identified.

408 Underground coal gasification is considered to be appropriately addressed by the existing arrangements for regulation of hazardous installations. In particular, COMAH and the Borehole Sites and Operations Regulations 1995 (BSOR) would apply to UCG operations. BSOR imposes a duty on operators to produce a health and

safety document for the site with particular emphasis on precautions against fire, explosion and the presence of harmful gases. Duty holders must also notify HSE prior to the commencement of drilling operations.

409 Although coal bed methane extraction is unlikely to fall within the scope of the COMAH Regulations, Part IV (Wells) of the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 (DCR), BSOR and the HSW Act would apply in full. Consequently, the existing regulatory framework is considered to be appropriate for controlling this activity.

Standards

410 Several internationally recognised codes are in place for the design and fabrication of pressure equipment. These include the European standard EN 12952 and the American Society of Mechanical Engineers ASME 1. These standards are regularly peer reviewed and revised when considered necessary.

Conclusion

411 Cleaner coal combustion technologies are refinements and developments of mature techniques. Their deployment will be underpinned by a large amount of existing relevant operational experience, knowledge and understanding. Consequently the risks to safety from their use in are acceptable, subject to certain points that are noted in paragraphs 412 to 418.

412 The gasification stage of IGCC is essentially a refinement of a mature technology that was last operated on a significant commercial scale almost half a century ago. Consequently, much of the first-hand operational and regulatory experience of this technology has been lost. Notwithstanding this, nor the high level of manual intervention under challenging conditions that the process is likely to require, it should be possible for the risks associated with IGCC to be controlled and kept at tolerable levels.

413 The use of underground gasification technology will require continuing attention. The extent of the potential hazards and the difficulty in controlling and monitoring the operation deep underground are considerable. Knowledge and experience of recent underground coal gasification is limited. More information and understanding regarding the range and magnitude of hazards and the likely effectiveness of suitable risk control measures is necessary if an appropriate safety evaluation of future developments is to be made. These issues 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. However, participation in international research and demonstration projects is likely to be an effective way in which duty holders and regulators can jointly develop their understanding.

414 Coal bed methane extraction does not present any significant new health and safety challenges. The hazards are well known and understood by the regulator and

the coal and oil/gas sectors. There is, however, a need for further information on the risk profile presented by the use of carbon dioxide to enhance methane recovery.

415 The important areas of concern regarding the risks from above-ground cleaner coal technologies are associated with the current state of knowledge regarding the behaviour of new materials under more arduous conditions and the practicability of carrying out physically demanding maintenance work in hazardous environments. Some of the advanced construction materials used in supercritical steam systems have only recently been developed and are operating under very demanding conditions. There is much less knowledge about the corrosion behaviour of these new materials under supercritical steam conditions than about those used in traditional subcritical boilers. Maintenance and inspection schemes should therefore reflect the extent of uncertainty until it has been effectively eliminated by experimental work and the collection and dissemination of relevant plant experience.

416 The materials used in gasification equipment face demanding conditions. The substances used and produced during the process are corrosive or erosive, difficult to contain and could cause premature fracture of unsuitable materials. Furthermore, 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.

417 Experience from previous UK coal gasification operations and recent international IGCC installations indicate that this process has a high maintenance demand, especially during the early years. It is prone to produce very hazardous tars, high melting point solids and dusts that block up heat exchangers etc. In most cases, manual cleaning is the only practicable way to clear these blockages. Effectively implementing appropriate risk control measures in a practicable manner for these activities is likely to present a significant challenge.

418 In conclusion, 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 GB 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 consequently 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.

8 CONCLUSIONS

419 There is, in Great Britain, a mature and well-established system of control of the risks to workers and the public arising from work activities, underpinned by legislation and both international and domestic standards. This system is flexible enough to deal with new risks and hazards, achieving sensible risk management. 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 particular energy developments described in chapters 2 to 7.

420 Important features of this system of health and safety at work law are that it is both comprehensive and flexible. 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 mentioned in chapter 3) is immediately subject to legal requirements on those working with the new technology to achieve acceptable standards of safety. Specific new regulatory controls are not needed, though these may follow (for example, to impose authorisation requirements) if the risks are sufficient to merit such action.

421 The risks related to the new energy developments discussed in this report can be seen as falling 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, most obviously from nuclear power generation, which require highly specific regulatory controls.

422 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.

423 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. This is particularly important when new technologies are developed (for example, in relation to carbon capture) or technologies that process engineers are less familiar with (such as biomass technologies) expand. It is also particularly important in relation to distributed generation, as 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, is kept under review.

424 Second, the overall framework of control needs to be kept under continuing review by regulatory organisations. It should be recognised, in maintaining this oversight, that in some areas regulation is more difficult, an example being distributed generation, which will involve either new technology or established technology operating in novel situations, frequently retrofitted into environments that are characterised by low user-skill levels. This creates a need for attention to communication and education, in the case of distributed generation of installers and domestic users.

425 Third, where we have identified further research needs (see, for example, comments on carbon capture and storage in paragraphs 149 to 151), 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 (those who undertake the activities that lead to the risks that need to be understood and controlled). There is, however, a responsibility on the organisations that exercise regulatory oversight to facilitate and assist where necessary.

426 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. It is fully adequate in relation to biomass and distributed generation, and we have no areas to suggest where review is needed in relation to these technologies. In relation to other technologies, we have identified a number of areas where a more specific review of current arrangements is required, and these are detailed in paragraphs 428 to 443.

427 The urgency and priority that attaches to these areas for further consideration will depend on the decisions the Government takes at the conclusion of the energy review. We will further examine what is needed, to what timetable, in the light of those decisions. None of the areas for further review identified below requires urgent action today, but it is essential that HSE remains closely involved with the planning activities across Government that will be required to take forward the conclusions of the energy review so that the required action can be taken to the appropriate timetable.

Gas storage

428 There is a need to review the suitability of some parts of the current legal framework. Specifically:

- The COMAH Regulations do not apply to storage in onshore strata. This could appear anomalous, as salt cavity storage is covered by the COMAH Regulations. In addition, some European Community countries are interpreting the Seveso Directives (Seveso I and II, see Annex 2) as applying to strata storage, which implies that the COMAH Regulations (which implement the Directive) should be applied to such storage. With this technique of gas storage liable to be developed at further sites in future, it

would be sensible to seek consistency of interpretation within Europe of the Seveso Directives. A consistent approach will be sought, and amendment of COMAH considered.

- HSE has considered amendments to PSR, which would require mandatory testing of off-site pipeline emergency plans. The current requirements are inconsistent with other major hazard legislation and will be reviewed.
- LNG import facilities are not currently specifically referred to in the Gas Safety (Management) Regulations 1996 (GSMR). However they could play an important role in minimising the risk of a gas supply emergency. Therefore, to ensure that the duty of operators of these facilities to co-operate with the National Transmission System (NTS) operator is clear, HSE will consider proposing an amendment to GSMR to include LNG import facilities.
- A new 'Application Outside Great Britain Order' (AOGBO) may be needed to apply the HSW Act to the possible development of offshore LNG terminals.

Carbon capture and storage

429 There are issues that need to be reviewed in the fields of research, standards, and the further examination of the regulatory framework to ensure that CCS projects are adequately covered.

430 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 need for modelling techniques to handle the complexity of behaviour following a leak or other loss-of-containment event need to be addressed.

431 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 accurately predict 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.

432 This is best developed 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.

433 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.

434 Second, in relation to standards, the lack of internationally recognised standards and codes of practice specifically for dense phase CO₂ 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 BSI and ISO, working together to address this important issue. Though the responsibility rests squarely with the industry, HSE will seek to facilitate progress.

435 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 the general management of health and safety, the established technology areas of major hazard sites, and occupational hygiene.

436 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. This will be examined in detail in appropriate research programmes and, if concerns are confirmed, consideration will be given to the amendment of current regulations. 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.

Wind, wave and tidal power

437 Existing regulatory arrangements are sufficient to deal with an expansion of energy production from these sources. However, a potential lacuna relating to offshore wind farms beyond 12 miles is noted. While existing wind farms are within the territorial sea, future farms may be built outside the 12-mile limit and would not attract GB health and safety legislation. A possible extension of the Act's application to cover any such future builds will be considered.

438 In relation to onshore wind farms, there remains a need for adequate guidelines for planning authorities that detail legal requirements, relevant standards and industry good practice. HSE will continue work with all relevant parties to facilitate the production and maintenance of such guidelines.

The generation of electricity by nuclear power stations

439 While there are no significant changes in the legal provisions relating to the development of a further generation nuclear power stations required, there will continue to be evolution in administrative processes. The current statutory provisions constitute a well-established and acceptable framework of regulatory control.

However, HSE intends to consider further development of the arrangements for pre-licensing assessments of candidate designs, as set out in Annex 2.

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

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

441 Phase Two would be site and operator specific and is HSE's assessment to support 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, we would anticipate that Phase Two may take approximately six to twelve months if the applicant provides a detailed and adequate submission and assuming other permissions (for example planning, Electricity Act) are forthcoming.

442 This process will achieve sufficient oversight of the process to achieve acceptable levels of safety and public reassurance, and 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. It will enable HSE to fulfil its responsibility for ensuring that any operators of nuclear licensed sites properly protect people and society from the nuclear hazards they control. However, to achieve this, additional resources will be required in NII.

Cleaner coal technologies

443 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 GB 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 therefore 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.

ANNEX 1: THE COMMISSIONING LETTER FROM MALCOLM WICKS MP, THE ENERGY MINISTER

10 January 2006

Geoffrey Podger
Chief Executive
Health and Safety Executive
Rose Court
2 Southwark Bridge
London SE1 9HS

In the context of the Energy Review, I am writing to request an expert 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.

As you will be aware, the Prime Minister and the Secretary of State for Trade and Industry announced a review of energy policy on 29 November 2005. The Review will aim to ensure the UK is on track to meet the medium and long-term goals set out in the 2003 energy white paper.

The Review will be broad in scope, looking at both demand and supply aspects, including transport and energy efficiency. It will look at a wide range of options to help put the UK on track to deliver these goals, including the role of current technologies such as civil nuclear power, renewables, cleaner coal, carbon capture and storage, and gas.

In order to make a full assessment of these options in time for the Review to publish its recommendations, we need an assessment by the HSE of some of the risks associated with new developments in the energy sector and their approach to ensuring industry manage these risks. This report will help the Review to put forward workable policy recommendations that do not threaten public or workforce safety.

The Review needs an assessment of the potential health and safety risks arising from some recent and potential future energy developments listed below (although this list

is not exhaustive) and the HSE's approach to ensuring these risks are managed sensibly by industry:

- 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 for candidate designs.

On nuclear, we would like an assessment from HSE of how they might go about the appraisal of reactor designs in advance of specific proposals for new build. This will be useful for the Review making a recommendation in taking the decision on whether there is a potential role for a new generation of nuclear power stations to help us meet our medium and long-term energy goals.

In order for the Review team to properly assimilate the report and make a considered assessment in advance of the Review making policy recommendations this Summer, we would need to have the final HSE report by end-June. Officials from the Review team have been working with HSE officials in preparation for this request and will remain in close contact throughout the process to share emerging findings.

We will be including a line in our Energy Review consultation document that will be published on 23rd January; both HSE and DTI officials have agreed the form of words. This would be the formal announcement of our request and until this date, the letter would be restricted. The HSE report will ultimately be in the public domain (as would any other consultation responses).

Any consultation or other engagement with the public that the HSE wish to carry out in preparing this report would help contribute to the Government's commitment to full public engagement throughout the process of the Energy Review and would have my support.

I am copying this letter to Lord Hunt (Parliamentary Under Secretary of State, DWP); Bill Callaghan, Chair of the Health and Safety Commission; Rt Hon Margaret Beckett (Secretary of State, Defra); Elliott Morley (Minister of State, Climate Change and Environment) and Lord Drayson (Parliamentary Under Secretary of State for Defence and Minister for Defence Procurement).

MALCOLM WICKS

ANNEX 2: THE POTENTIAL ROLE OF NUCLEAR PRE-LICENSING ASSESSMENTS FOR CANDIDATE DESIGNS

Introduction

1 Chapter 6 of this report sets out our views on the control of risks associated with the generation of electricity by nuclear power stations. As indicated there, this Annex provides more detail on the on the issue of pre-licensing assessment.

2 The Energy Minister asked HSE for advice on the health and safety risks associated with some specific energy developments, including consideration of a new generation of nuclear power stations. In addition the Minister asked HSE for advice on the potential role of pre-licensing assessments of candidate designs in the event of new nuclear build. It asked for an assessment of how HSE might go about the appraisal of reactor designs in advance of specific proposals for new build.

3 To respond to this request, HSE has undertaken a review of its regulatory strategy for licensing new nuclear power stations. In doing so, HSE has been mindful of the objective set by HSC when it responded to an earlier Government review of the prospects for nuclear power (the *Nuclear Review*) in 1994. This was ‘to ensure, through the regulatory processes and the framework of legislation, that all licensees – existing and new – continue to maintain, or where reasonably practicable enhance, the existing high standards of health and safety achieved by the UK nuclear industry’.

4 This annex reports our conclusions. It summarises:

- previous experience of pre-licensing;
- previous (1994) regulatory review related to potential new build;
- significant changes since 1994;
- HSE’s initial review of the issues to be considered;
- our stakeholder engagement exercise;
- feedback from the international regulatory review team assessment of NII;
- implications of HSE’s review of its Safety Assessment Principles for new nuclear power station design standards; and
- the process proposed for future pre-licensing assessments.

5 We have endeavoured to look critically at our processes, taking account of the views of others, to explore the potential for improving our effectiveness. At the same time, we need to fulfil our obligation to ensure that any new designs comply with UK legislation.

Previous experience of pre-licensing

The Sizewell B experience

6 Sizewell B was the last nuclear power station built in the UK. As a project, it had a long and convoluted history stretching back to the mid-1970’s, when the Central

Electricity Generating Board (CEGB) began expressing interest in the pressurised water reactor (PWR) as a contender for its next tranche of nuclear power stations. Around 1973, NII embarked on a limited review of the generic safety aspects of light water reactors. The NII review was not related to any application for a site licence, and can therefore be considered as a ‘pre-licensing’ review. As interest in PWR technology increased, the Government encouraged NII to complete its review and a report on the generic safety aspects of PWRs was submitted to the Secretary of State for Energy in 1977. That report said that there were no fundamental safety reasons why a PWR could not be licensed in the UK. A more comprehensive report on generic PWR safety was issued by NII in 1979.

7 CEGB did not apply for a licence to build the reactor at Sizewell until January 1981, but NII had engaged in discussions with the company and the reactor design authority (NNC) over the previous two years or so, up to the licence application. Those discussions, all of which constitute ‘pre-licensing’ activities, were vital to ensure that all parties agreed on the requirements and timings for safety case submissions, and NII’s assessment and permissioning process. By the time CEGB had applied for the licence, there was a detailed, agreed programme of safety case submissions through to start of construction, the first permissioning hold-point. Other permissioning hold-points were identified in that original programme extending through construction, to commissioning and full-power operation. The key milestones leading up to the granting of a licence for Sizewell B are given in the table below.

TABLE. Key milestones leading to the grant of a licence for Sizewell B

Milestone	Date
Application for section 2 Consent*	January 1981
Application for nuclear site licence	January 1981
Draft pre-construction safety report (PCSR) submitted to NII	December 1981
Public inquiry	January 1983 to March 1985
Public inquiry report published	January 1987
Section 2 Consent granted	March 1987
Final issue of PCSR	May 1987
Nuclear site licence granted	June 1987

* Before the introduction of the Electricity Act 1989, Consent was required under section 2 of the Electricity and Lighting Act 1909

8 Although a prospective licensee may carry out a certain amount of preliminary work at a proposed reactor site (such as ground clearance and other groundwork preparatory to later construction), planning law restricts any substantive construction. More particularly, if any construction work is an integral part of a proposed power station, then the licensee will require Consent to proceed from the relevant Secretary of State under Section 36 of the Electricity Act 1989. The Nuclear Installations Act

1965 also requires that a licence must have been granted by HSE to allow the installation and operation of a nuclear power station.

9 These various legal requirements mean, in effect, that while a licensee may undertake some initial site works (at his own commercial risk) he cannot begin substantive construction (for example, pouring concrete for the foundations) until both the Nuclear Site Licence and section 36 Consent have been granted (along with any necessary additional local planning permission).

10 For major construction projects, the Secretary of State can call a public inquiry and Sizewell B was no exception. The effort put into preparation (by all parties) for such an inquiry was considerable – hence the delay of 18 months between the inquiry’s announcement and its start in January 1983. The inquiry lasted until March 1985, with the Inspector’s report not being issued until December 1986. section 2 Consent (and deemed planning approval) was granted in March 1987, with HSE granting a site licence in June 1987.

11 With the various consents out of the way, CEBG’s projected construction time for Sizewell B was 72 months from start to fuel load. This was achieved within a fortnight of the projected programme.

12 Overall, NII expended well over 150 staff years of effort on the PWR project between 1973 and 1995. The published NII report on generic PWR safety ('A Report by the Health & Safety Executive to the Secretary of State for Energy on a review of the generic safety issues of pressurised water reactors, HSE 1979, ISBN 0 11 883653 6') quotes 12 staff-years of effort on the review between 1976 and 1977 alone. The total expenditure of effort on the generic reviews of LWR/PWR safety (which lasted from 1973 to 1979) was clearly much greater than that. In addition, there was a large NII resource committed to the Sizewell B Inquiry and the assessment process leading to the granting of the licence. From granting the licence to full power operation, NII expended a further 107 staff-years of inspector effort. Overall, it is estimated that well over 150 staff-years of specialist NII inspector time were absorbed on the PWR between 1973 and Sizewell B entering full operation in 1995.

13 It may be seen from this that the process for licensing Sizewell B was effectively divided into three-stages comprising pre-application (ie before a licence application was made), pre-licensing (ie before the granting of a nuclear site licence) and post-licensing assessments. The pre-licensing process was not well documented in advance and, on completion, many hundreds of technical issues remained unresolved. Thus when the licence was granted and construction commenced, the licensee carried significant regulatory uncertainty. Also, because of the outstanding safety issues and the ongoing development of the detailed design and safety case by the applicant, the safety case had to be revisited and reassessed by NII throughout the construction and commissioning phases, thus giving rise to the potential for safety issues to arise late in the project.

The Hinkley Point C experience

14 In August 1987, CEBG applied for regulatory consent to construct a PWR at Hinkley Point C. The design was based closely on the design of the station at Sizewell

B. The Secretary of State once again called a public inquiry, which started in 1988. The scope of the inquiry was more restricted than that at Sizewell, with far less attention to the details of the reactor design and its safety, but nonetheless the inquiry still lasted 182 days (cf. 340 for Sizewell B). The inquiry also absorbed considerable HSE/NII resources. The inquiry inspector issued his judgment in 1990 and section 36 Consent was subsequently granted.

15 In 1990, the CEBG was broken up into parts with the nuclear stations going to Nuclear Electric and Scottish Nuclear. Following this restructuring, the Hinkley C project was halted. However there were important lessons learnt. If a standardised or replicated design is used, the design and safety case are well developed much earlier in the project, thus leading to reduced regulatory assessment timescales and reduced regulatory uncertainty.

Lessons from previous experience

16 The approximately six-year gap between the CEBG's application for and granting of a nuclear site licence to build and operate the PWR at Sizewell may be compared with the gap of about two years just a few years earlier for this same process to be completed with the last two power stations in the AGR series, at Heysham 2 and Torness. A number of factors appear to have contributed to the extended timescale for licensing Sizewell B.

17 First, the Heysham 2/Torness proposals were an evolution of a well-developed AGR design that had already been licensed on a number of UK sites, whereas Sizewell B was the first proposal to build a PWR power station in the UK. The introduction of PWR technology new to the UK resulted in both the applicant and regulator needing a longer lead time in order to develop an understanding of this technology.

18 Second, the application followed shortly after the accident at Unit 2 of the Three Mile Island nuclear power station in the USA. Although this did not lead to any significant off-site radiological consequences, large parts of the reactor core melted in this accident resulting in lengthy clean-up activities and the end of Unit operation after less than a year in service. The accident highlighted the important role that reactor containment may play in mitigating the consequences of such severe accidents and prompted a realisation that despite stringent design measures to reduce the likelihood of such severe accidents to very low levels, it is also necessary to understand and mitigate their consequences when this is reasonably practicable.

19 As a result, a large international research programme into severe accidents and their mitigation was undertaken throughout the 1980s, and the Sizewell B design was enhanced over the same period to reflect the developing understanding. Changes to the design and the introduction of measures to address severe accident concerns also increased the regulatory resource needed to assess this licensing application. The Chernobyl accident in 1986, which resulted in the release of a substantial fraction of the volatile radioactive inventory of the core into the environment, reiterated the need for both safety in design and severe accident management measures.

20 Finally, a major public inquiry was held in parallel with HSE's assessment of the licence application, into the planning application to build the proposed power station. Although separate from the licensing process, HSE was asked to participate in this inquiry and in common with all other participants, had to expend significant resource in presenting its evidence and preparing for cross-examination. Sir Frank Layfield, the Inspector conducting the inquiry, concluded that 'NII's approach to design and safety assessment are sound....NII demonstrated an impressive degree of technical competence.....NII possess a sufficiently high degree of engineering and managerial competence to ensure plant safety'.

21 Interestingly, at that time there was a less open routine access to knowledge about safety issues, regulatory processes, assessment approaches and guides, etc.

22 We believe that any potential changes to HSE's future licensing strategy and the planning process must continue to maintain public and other stakeholders' confidence in HSE's NII as a strong and independent nuclear regulator.

Previous regulatory review related to potential new build

23 A significant review of the UK nuclear regulatory regime was published in 1994. In it, HSC provided advice to the Government on the suitability of the legislative and regulatory systems for dealing with any decision to construct nuclear power plants in the UK.

24 HSC concluded that the legislative and regulatory systems were comprehensive, internationally recognised, vindicated by public inquiries, and that there was no reason to change them in any fundamental way to deal with changes to the nuclear industry or new construction.

Significant changes since 1994

25 Since the last review of the nuclear licensing system in 1994, there have been significant developments in the UK nuclear industry and in society as a whole, which we need to take into account.

26 The CEGB has gone and the industry has been through privatisation, liberalisation and extensive restructuring. New build is likely to be commercially financed, not fully Government funded, and this increases the need for a clear, well-defined regulatory process and one that engenders public and other stakeholder confidence in the regulatory regime.

27 The industry restructuring has resulted in competitive pressures, which in turn have led to a tendency for nuclear companies to reduce their in-house technical resource. So we now find that there is an increase in issues associated with the controlling mind of the site owner or licensee parent company, contractorisation, etc. In addition, NII needs to ensure that the site licensees remain 'intelligent customers' who are in control of the work on their sites and who have the knowledge to understand the hazards they are creating and how to control them, and manage effectively the work of their contractors.

28 As well as the effects of staff reductions, there have been further challenges arising from the skewing of the age profiles of staff within the industry and its ability to retain knowledge and experience.

29 A further important aspect is that the nuclear industry has improved its openness and public engagement since 1994. In addition, developments such as the Freedom of Information Act have led to increased public expectations on openness and for the transparency of Government and regulatory decisions.

30 There have also been significant international developments in safety standards, the global nuclear industry, and in the markets since 1994. The International Atomic Energy Agency (IAEA) has been developing nuclear safety standards and guidance for several decades. These were initially intended to help countries adopting nuclear power technologies, but from the early 1990s they have been developed further so as now to represent good practice, and in some cases best practice, for the whole international community. As a result, the gap between the national safety requirements of different advanced countries and IAEA safety standards and guidance has been greatly reduced and in some areas eliminated. HSE has itself benchmarked its nuclear Safety Assessment Principles (SAPs) against IAEA standards and used the Western European Nuclear Regulators' Association (WENRA) reference levels during its current review of the SAPs. As a result, we believe that it is now possible for the national nuclear safety standards of different countries to converge around the IAEA Safety Standards. This was foreseen in the mid-1990s, for example in the former HSE Director General J D Rimington's presentation *Improving international safety standards* to the British Nuclear Industry Forum International Conference on 29 June 1993. There are already several vendors marketing power reactor designs that claim to meet international safety standards which may result in nuclear power plant vendors developing advanced designs that are licensable in a number of countries without fundamental modifications to existing regulatory approaches.

31 As a result of these developments, we have recognised that we may need to enhance our regulatory strategy:

- to maintain the effectiveness of our nuclear licensing regime as the industry, both within the UK and internationally, changes;
- to make the most effective use of our resource, especially by looking for synergies with the work of nuclear regulators in other countries; and
- to enhance stakeholder and public confidence in the robustness of the regulatory system by being more open about what we do.

32 The 2006 Energy Review has therefore given us the opportunity to look again at our regulatory approach to address these matters.

NII's initial review of the issues to be considered

33 As a starting point for its contribution to this report, NII reviewed the issues arising from the previous experience and the previous regulatory review report. In addition, it considered what changes there had been since 1994. The result was a series of issues requiring further consideration that can be summarised as follows:

- Design assessment: At present we grant a licence to the operator of a particular site to undertake specific activities. There may be regulatory advantages in de-coupling our assessment of the reactor design from our assessments of the site and the eventual operator. This could allow us to issue some form of formal opinion on whether the generic reactor design could successfully form one of the three key elements (installation design safety case, organisational capability of the applicant and siting issues) that form the basis for considering granting a nuclear site licence. (This is the approval process used in some other countries.)
- Taking account of international work: Some current designs of nuclear reactor are undergoing regulatory assessment in other countries and both the licence applicant and HSE might be able to take advantage of this work.
- Making our processes more transparent, clear and predictable: The flexibility inherent in HSE requirements for programmes of licensing sites and assessing safety submissions may make our nuclear safety assessment and licensing process appear uncertain. We believe we should make our process clearer to reduce uncertainty and enhance transparency.
- Public confidence: To maximise public confidence in our processes, we wish to ensure that they are more easily understood, and to give the public more opportunity to express their opinions and concerns to us.
- Resources: HSE would need additional resource to enable it to assess any significant new nuclear power station build proposals while continuing to meet current plant regulation commitments.
- Standards: We will ensure the standards we apply remain up to date, incorporate relevant good practice, and reflect international developments.
- Siting: It is many years since some of the DTI policies on siting were developed and there is now an opportunity to review them (see paragraph 102 of this annex, below).

Stakeholder engagement exercise

34 To help us develop our thinking on these issues and to promote greater transparency, HSE embarked on a focused stakeholder engagement exercise. We summarised the above issues in a document and invited a large number of stakeholders to a workshop to discuss them with us on 3 March 2006.

35 We used the feedback from the debates to confirm that the issues we had identified were those of most interest or concern to stakeholders. We consolidated these issues into a list of 29 questions which we posted on the HSE website and we invited public comment on these during April 2006. A significant number of responses were received, including comments from the public, licensees, reactor vendors, and non-Government organisations (NGOs). As anticipated from such diverse groups, the range of comments was large with differing views expressed.

36 We have endeavoured to take account of the general tenor of these comments as we have formulated our thoughts on the process proposed for future pre-licensing assessments.

37 A summary of stakeholder comments and HSE's responses will be posted on the HSE website, taking account of any confidentiality requirements expressed by respondees.

38 In our proposed pre-licensing process, described below, we have included further opportunities for gathering the views of the public and other stakeholders.

Feedback from the international regulatory review team assessment of NII

39 To test the capability of our nuclear regulatory regime to respond to any new nuclear build proposals, we proposed to Government that it invite an international team of nuclear safety regulators to conduct a peer review of our organisation and regulatory activities. This team was led by IAEA as part of its International Regulatory Review Service (IRRS) and was made-up from IAEA staff and senior members of overseas nuclear regulatory bodies, including the heads of some of these bodies.

40 The IAEA IRRS programme assists United Nation Member States to enhance the organisation and performance of their nuclear safety regulatory bodies and systems. It looks at the national legal system, and the functions of reviewing and assessing safety submissions; licensing nuclear safety activities, establishing regulations and criteria; inspecting nuclear facilities and enforcing national legislation. The IRRS missions focus on all these aspects in assessing the regulatory body's safety effectiveness. Comparisons with successful practices in other countries are made and ideas for improving safety are exchanged at the working level.

41 An IRRS mission is made only at the request of a Member State. It is an objective review of nuclear regulatory practices with respect to international guidelines. It provides an independent, international assessment of work processes that may identify areas for improvement. Through the IRRS programme, the IAEA facilitates the exchange of knowledge and experience between international experts and regulatory body personnel with the aim of enhancing nuclear safety in other nuclear countries.

42 The specific purpose of the IRRS mission to HSE was to evaluate the regulatory effectiveness of both the current HSE regulation of existing nuclear power plants and our readiness to regulate and licence any new reactor designs. This was in the context of there not having been any new build of a reactor in the UK since the 1980s.

43 The report of the mission has been published on HSE's website www.hse.gov.uk/nuclear/regulatoryreview/index.htm. The IRRS team identified a number of good practices within NII and these will be publicised worldwide for the benefit of other countries. These good practices included:

- the mature and transparent regulatory system and the advanced review process;
- highly trained, expert and experienced staff; and
- a flexible regulatory regime that sets clear expectations for the licensees and permits NSD to make decisions on well-justified technical grounds.

44 The IRRS also identified a number of suggestions and recommendations for improvement. These included to:

- Establish an appropriate budget and staffing levels to accomplish all assigned work;
- Improve the independent capability for safety analysis in specific areas;
- Improve operating experience feedback assessments and follow up the corrective actions.

45 Specifically on the topic of potential new build, the IRRS team recommended that NSD should develop and document the authorisation process for new build including step-wise licensing and guidance for the potential applicant. The team also stated that, in case of receiving a new application for a nuclear power plant, NSD has to acquire significant additional resources in order to meet its current responsibilities and to meet this new challenge. In addition, the IRRS team provided some expert opinion regarding the planning and execution of new build activities.

46 We believe that the results of the IRRS mission have given independent confirmation of the strengths of the UK nuclear regulatory regime. We aim to take the recommendations and suggestions for improvement forward positively. We welcome the IRRS expert advice on the new build aspects and we have taken this into account in preparing this report, particularly in identifying the processes we suggest are applied to pre-licensing of candidate designs.

Process proposed for future pre-licensing assessments

47 We identify here our suggested process for future pre-licensing assessments for any UK new reactor build programme. In developing these proposals, we have considered different options and have taken account of:

- the paramount importance of securing nuclear safety;
- the responses to the stakeholder engagement exercise;
- the advice of the IRRS team;
- advice and experience of HSE staff;
- discussions with other regulators involved in the UK nuclear industry; and
- nuclear regulatory practices in other countries with new build programmes and discussions with other nuclear regulators.

48 In developing the proposed process, we have held several objectives in mind:

- build upon the proven UK nuclear regulatory process, to protect people and society, ensuring risks are adequately managed;
- ensure a rigorous, robust and transparent examination of new build proposals;
- recognise the need for more opportunities for the public and other stakeholders to comment on safety issues on an informed basis than has been the case in the past;
- ensure our process is clear and transparent both to the public and to the industry;

- minimise uncertainties;
- make the steps in the process clearer;
- allow for advice from overseas regulators to be taken into account to the extent that is appropriate; and
- suggest a timeframe that is adequate for NII assessment and that supports these objectives, given appropriate resourcing, adequate submissions and necessary responsiveness from those putting forward designs for assessment.

49 We have concluded that a multi-stage assessment and licensing process should be considered. This would have two phases: Design Acceptance, and Nuclear Site Licensing. We propose that Phase One is a four-step Design Acceptance process that is appropriately site and operator neutral. Phase Two is HSE’s assessment to support granting of a Nuclear Site Licence and is thus site and operator specific, given a satisfactory outcome of Phase One. These are expressed in tabular form below with approximate timescales. They are also shown diagrammatically in Figure 1 (process for Phase One) and Figure 2 (overall process including activities carried out by other bodies) included at the end of this annex. There could be some overlap of Phases One and Two. It should be noted that the precise timing will depend on factors such as the availability of suitable resource in NII, the quality and timeliness of the safety submissions received, the significance of any issues arising, the responsiveness of those putting forward the designs for assessment, the ability to make best use of bilateral contacts with overseas nuclear regulators, and their experience with similar reactor designs etc.

TABLE. Assessment and licensing process

Phase One: Design Acceptance		
Step	Process	Approximate timescale
1	Design and safety case submission based on generic site envelope	Applicant is responsible
2	Fundamental safety overview	3–6 months
3	Overall design safety review	6–12 months
4	Detailed assessment for design acceptance	2 years
Phase Two: Nuclear Site Licensing		
	Site Licence Assessment	6–12 months

Phase One: Design Acceptance

50 We propose that Phase One is a four-step Design Acceptance process that is site and operator neutral, with a duration of something in the order of three years after Step 1, as per paragraphs 51 to 67.

Step 1: Design and safety case submission based on generic site envelope

51 The applicant (a potential licensee, or a reactor vendor, or other consortium/partnership) submits a detailed design and safety case to HSE. This, as a minimum, has to be sufficient to make the next step practicable, with more information to follow during and ahead of the later steps. We are advised by vendors that the likely candidate designs are well developed and thus we would expect them to be able to provide a fully detailed submission at the start of the regulatory review process. This should include detail of the design and safety principles and criteria that have been applied by the applicant in their own assessment processes, together with details that establish the providence of the design (eg quality management arrangements, use of suitably qualified and experienced persons in its development, peer review arrangements, etc).

52 Although we refer to a design and safety case, it is important to note that we would take a holistic whole life approach. We would therefore expect the safety submission to cover not only the design, but also aspects such as construction, maintenance, operation, radioactive waste and decommissioning, although the depth will vary according to the significance of each issue to the design acceptance.

53 Assuming the applicant did not identify a specific site for the proposed plant, it would need to specify generic siting characteristics for a range of UK sites against which we would assess the effectiveness of the safety provisions incorporated into the design. We would expect these characteristics, such as distribution of local population, seismic hazard and extreme weather events, to envelope or bound the characteristics of likely UK sites or selection of sites so that reactors of this type could potentially be sited at any of a number of suitable locations. The licence applicant would then need to demonstrate that any specific site it proposed fell within the generic siting envelope in order to be granted a nuclear site licence.

54 Although we would expect the submission to describe how the reactor would be operated and controlled after construction, we envisage that this submission would not be operator specific.

55 It is anticipated that there would be a period of discussion between HSE and any applicants before any safety cases were submitted, in order to clarify HSE's expectations, the applicant's proposed programme and scope of submissions, and HSE's timescales for assessing the application and responding.

56 To ensure transparency and help prospective applicants, we anticipate issuing guidance to describe the details of the Design Acceptance process.

57 At the same time as submitting safety cases to HSE, we would expect applicants to place as much information into the public domain about their proposals as commercial-in-confidence and security considerations would allow, so that any interested parties might make representations to HSE on any relevant health and safety issues that concern them. We would expect this information to be made available in a form that facilitates other stakeholders to have an input. HSE would take these representations into account in coming to decisions and would publish a

report explaining how it had done so when it published its conclusions on Design Acceptance.

Step 2: Fundamental safety overview

58 This would be a short HSE review (say, 3–6 months) of the fundamental acceptability of the proposed reactor design within the UK regulatory regime. The idea would be to identify any major design aspects or safety shortfalls that would prevent the design being the basis for granting a nuclear site licence in the UK. This would help avoid HSE expending excessive resource on unsuitable applications.

59 Public comments would be invited on the safety case via our website and put into the public domain via the applicant.

60 The output from this would be a public HSE statement on the basic acceptability or not of the proposed design.

Step 3: Overall design safety review

61 This is a more in-depth HSE review (say, 6–12 months) of the safety aspects of the proposed design. We would judge the safety case in more detail against key aspects of our Safety Assessment Principles, such as passive safety, plant integrity, segregation and redundancy provisions, and protection against hazards. We would not typically examine in detail the underlying analyses that support these claims. One of the aims would be to identify if any significant design or safety case changes were likely to be needed to comply with UK requirements.

62 Public comments would be invited on the safety case via our website and put into the public domain via the applicant.

63 The output would be a public HSE statement identifying overall potential acceptability and listing safety issues requiring resolution during Step 4, plus any necessary modifications that have been identified.

Step 4: Detailed assessment for design acceptance

64 This would be an in-depth HSE safety assessment (say, 2 years) of the case submitted. This would examine all relevant aspects of the submission including more detailed ALARP assessments and may include inspections of the applicant's procedures and records and independent verification analyses by HSE or consultants to HSE. Additionally, it may include details of the procurement and quality management arrangements to secure compliance with the design intent.

65 Public comments on the safety case would be invited via our website and put into the public domain via the applicant.

66 The output would be a public HSE statement providing a Design Acceptance certificate (if successful). The accepted design will then be suitable for construction, once a licence was granted, on any UK site demonstrated to be within the generic siting envelope.

67 The model Design Acceptance certificate would be a clear short statement on the acceptability in principle of a licence application based upon the generic design without exceptions or caveats. Such a statement could only be given if the applicant had resolved all regulatory issues raised during assessment of the safety submissions to HSE's satisfaction. An applicant might wish, however, to receive a statement on an earlier date to meet a programme milestone, in which case the statement would identify those issues on which HSE had been satisfied by the applicant's submissions and those still outstanding.

Phase Two: Nuclear Site Licensing

68 Phase Two of the process is HSE's assessment to support granting of a Nuclear Site Licence. This requires assessment of the plant, the specific site and the operating organisation (who will become the licensee).

69 The design assessment should be a simple process referencing the Accepted Design. The site application to HSE should be a verification that the specific site is covered by the agreed generic site envelope, a suitable emergency plan is proposed, and that it conforms with Government siting policy. Other aspects of siting are discussed below.

70 We therefore see the main element of the Phase Two Site Licensing process as an examination of the prospective licensee's organisation for safe operation of the site. This will require the Applicant to submit a management prospectus and proposed Nuclear Site Licence Condition Arrangements, as required by HSE's *Notes for applicants for nuclear site licences*.

71 If the applicant provides a detailed and adequate submission we would anticipate HSE's Phase Two assessment would take around 6–12 months. As with Phase One, we will be taking steps to ensure the process involves as high a degree of openness and transparency as practicable.

Discussion of key elements of the multi-stage assessment and licensing process

72 In arriving at the process proposed above, the aspects discussed in paragraphs 73 to 114 below are significant.

Timescales

73 We have suggested indicative timescales within which such a process could potentially work. We believe these are realistic estimates, but only if the applicant's submissions are comprehensive, complete, of high quality and demonstrate that UK

health and safety requirements have been met including reducing the risk so far as is reasonably practicable. Additionally, they are based on an assumption of a suitably responsive approach by the applicant to any issues we may raise.

74 These timescales also assume that any design proposed would be an evolution of reactor technologies with which we are already familiar, for example those already in operation in the UK. The timescales may be extended if designs with which we have less familiarity were proposed.

75 Our assessment timescales will also depend on an appropriate level of the right resource being available within NII and available for support, and suitable access and co-operation with overseas nuclear regulators.

Resources

76 NII does not have surplus resource with which it could currently undertake the proposed multi-stage assessment and licensing process. Indeed, at present it is seeking to recruit to meet its current work programme and that foreseen for other sectors. Any pre-licensing programme would need to build in a lead time within which additional staff would be recruited and suitably developed.

77 This may be a significant issue for HSE as recruitment of appropriately qualified and experienced staff has proven difficult for NII in recent years.

78 If the resourcing issue is appropriately addressed, it need not necessarily lead to significant delays, since any prospective applicants would also need time to prepare their safety submissions. Furthermore, the multi-stage process proposed has smaller resource needs in the early stages, so we should be able to increase our staff resource in a managed and progressive manner. Additionally, it might be possible to obtain assistance with resourcing from close collaboration with overseas nuclear regulators and international organisations.

79 Ultimately, insufficient NII resource of the right quality will extend the timescales in which we can conduct our assessments.

Transparency

80 We accept that this is only an outline proposal. If a Government decision is taken to move ahead with a new build programme, HSE will provide more detailed guidance for prospective applicants, interested stakeholders and HSE's own inspectors.

81 We believe that the proposed multi-stage assessment and licensing process with this additional guidance would provide a clear and transparent basis for licensing new nuclear power stations.

Public involvement

82 We are proposing that the applicant places as much information into the public domain about its proposals and safety case as commercial-in-confidence and security considerations would allow, so that any interested parties might comment to HSE on any issues about the case that concern them. HSE would take these comments into account in coming to decisions during the Design Acceptance process and would publish a report explaining how it had done so when it published its conclusions. This proposal requires further development, particularly the requirement for vendors to provide information to the public.

83 We believe that this would maximise the opportunity for the public to input comments into the assessment process, while ensuring that HSE still bears full responsibility for nuclear regulatory decision making.

Regulatory uncertainty

84 We believe that these proposals respond appropriately to comments expressed by our stakeholders that the licensing process needs to be clear, with due certainty, work within reasonable timescales, engender public involvement and confidence, while maintaining the rigour of licensing. By identifying a Design Acceptance process where the design safety assessment may be completed before major investment in construction starts, regulatory uncertainty to the applicant is minimised. Furthermore, the proposals also provide safety benefits, since safety improvements that are reasonably practicable at the design stage may be progressively foreclosed as construction proceeds. It also provides enhanced opportunity for involvement of members of the public.

85 This concept of progressive reduction of regulatory uncertainty before significant investment in plant construction is made is shown diagrammatically in Figure 3. As the regulator's safety assessment progresses, the regulatory uncertainty will decrease with time until the regulator makes a final decision on whether or not to grant the applicant permission to proceed. Over the same period, the applicant's financial commitment and exposure to irrecoverable costs will rise as it invests in facility design, development of the safety case, site selection, pre-ordering of plant components with long lead-times for delivery, construction, training of staff etc.

86 For new reactor designs that have already been developed in detail by their vendors, particularly those that have received a large degree of regulatory scrutiny in their countries of origin, the commercial and project risks associated with preparing a detailed design safety submission have, we anticipate, already been taken. It should therefore be possible for a prospective nuclear power station licensee to submit a single detailed safety case to HSE for assessment, rather than a series of safety cases produced as the design develops. This would in principle allow a large step reduction in regulatory uncertainty in return for meeting the relatively small costs associated with HSE's assessment.

87 Regardless of the approach adopted in any particular case, however, HSE would undertake rigorous assessments of the applicant's safety submissions before granting any nuclear site licence, and construction could not commence before this. Additionally, we intend that it is a more open process with greater opportunities for public input than has been the case in the past.

Applicable standards

88 HSE assesses nuclear safety proposals to test whether they demonstrate that regulatory requirements, particularly that of reducing risks as low as reasonably practicable (ALARP), would be met if it gave permission for implementation. Its inspectors are guided in their judgement by HSE's nuclear Safety Assessment Principles (SAPs), which set out relevant good practice for a wide range of nuclear facilities. It is not a requirement that every individual SAP must be met in every case, but where a SAP is not met, the submission needs to demonstrate that the overarching ALARP requirement is still satisfied. The current SAPs were published in 1992 following the end of the Sizewell B Public Inquiry.

89 An exercise to review and revise the SAPs was started around the tenth anniversary of their last publication, with the aim of updating them in the light of experience and extending their scope into areas such as organisational factors and clean-up and decommissioning of old facilities. As part of this review, HSE has sought comments from a wide range of stakeholders via workshops and by placing developing drafts on its website for public comment. It has also taken the opportunity to benchmark the SAPs against the IAEA's nuclear safety standards and by using the WENRA reference levels.

90 This exercise is now drawing to a close and HSE is confident that the revised SAPs (due to be issued later this year) will reflect modern international nuclear safety standards and will provide appropriate, proportionate guidance to its nuclear inspectors for a further 10 years. They should form a stable basis for HSE assessment of any proposals for new nuclear build, one that has had the benefit of stakeholder engagement.

Credit for overseas regulator assessments

91 We consider that there is scope for HSE's assessment activities to benefit from any assessments of proposed designs undertaken previously by overseas nuclear safety regulators. We would take the findings of such work into account within the Design Acceptance Steps as appropriate. HSE conducts its assessments on a sampling basis and therefore the availability of additional information would help us to target our resources to best effect.

92 The extent to which we might take these assessments into account would depend firstly on the depth of information provided by the applicant on the regulatory issues identified by overseas regulators and the evidence it submitted on their resolution. It is the responsibility of the applicant to demonstrate the safety of its

proposed reactor designs, not for HSE to assemble information on regulatory issues resolved overseas and make the case on the applicant's behalf. HSE would then test the robustness of the claims made for resolution of overseas regulatory issues by direct discussions and correspondence with the relevant regulators. The weight that we would give to this information in our regulatory decision making would depend upon the scope of our formal information exchange agreements with the overseas regulator, the knowledge we had gained of the overseas regulatory system from those exchanges, and the willingness of the overseas regulator to engage with us on issues of primary interest to the UK, including providing access to detailed information.

93 It is, however, the duty of each sovereign state to conduct an appropriate safety assessment of proposals for new nuclear build in accordance with the national regulatory requirements of the host country. We would therefore not simply accept that a regulatory issue had been resolved because an overseas regulator had considered the same issue and had agreed its resolution. We would consider the weight of evidence for ourselves, test whether overseas assumptions (eg on plant operating regime) would remain valid if the technology were adopted in the UK and conduct our own assessment against UK requirements. These of course include the legal requirement to demonstrate that the risks have been reduced to a level that is ALARP.

94 It should also be noted that, of the most likely candidate designs, no operating licence has yet been granted in any western country, as national programmes have not yet progressed this far.

'Off-the-shelf' designs

95 Some nuclear proponents have expressed interest in the concept of international 'off-the-shelf' designs that could potentially be built identically in different countries and should, according to these proponents, be judged against common international standards. They see this as a means of driving international competition and reducing costs. We view this as impracticable at present. As noted already, assessment is required by each host country, to its own standards. Furthermore, timing differences between build programmes of different countries would likely mean that there would be small or local design evolutions, and potentially large changes, which would result in additional assessments being required. There is already evidence of some divergence in design between the European pressurised water reactors (EPRs) being adopted in Finland and France.

96 Regarding HSE's proposed multi-stage assessment and licensing process, we propose that any Design Acceptance certificate issued would be valid for that generic design for a period of 10 years. Any proposed changes to the design would need reassessment on a case-by-case basis.

Recovery of HSE costs

97 HSE recovers the full cost of its regulation of each licensed nuclear site from the site licensee under the Nuclear Installations Act 1965 (as amended). This includes

charging applicants for nuclear site licences for the work HSE undertakes in relation to their applications before any licences are granted. It would be necessary for HSE to recover the costs associated with any pre-licensing work in a similarly suitable way from non-licensees. Further work will be required to confirm the mechanism for this.

Parallel assessment of different designs

98 As already noted, HSE would need to recruit additional nuclear inspectors to respond to any requests for either pre-licensing assessments of new reactor designs or applications for nuclear site licences for new power stations. The required additional resource would increase in some relationship with the number of reactor designs and the novelty of those designs in the UK. Without the ability to acquire suitable resources, HSE's assessment timescales could be extended significantly beyond those indicated earlier. Furthermore, subsequent applications could potentially divert HSE resource from assessments already underway and put programme timescales at risk. The number of applications that HSE might receive and their timing is currently unknown.

99 Therefore, to enable proper programming of recruitment and management of its resources, HSE would require prospective applicants to give us advance information of the likely scope and timing of their applications.

100 A proposal to address this issue is to provide a 'submission notification window'. During this time expressions of intent to lodge Design Acceptance applications could be invited. HSE would use this information to help plan and manage its resources and to indicate likely assessment timescales. Any applications received later may need additional resource, which could cause delay.

101 If requests for pre-licensing assessments of a large number of different designs were received, the practicalities of recruitment and development of the new recruits into effective nuclear regulators would limit the speed with which HSE could progress simultaneous assessments. This suggests that applicants should co-ordinate their approaches to HSE and agree common priorities for assessment.

Site selection and public inquiry

102 The nuclear site licence applicant has to identify the site on which it proposes to build a nuclear power station and there are three main aspects to this on which it must satisfy HSE. First, the design safety case must show that the plant would have robust defences against a range of external hazards, including seismic disturbances and extreme weather events such as flooding. The second relates to the ability to derive an adequate emergency plan and evacuate if necessary – aspects such as the proximity of schools, hospitals and prisons are relevant here. Finally, the proposal must conform with Government siting policy, which relates to population density in the vicinity of proposed sites and is intended to limit the number of people that might be affected in the very low probability event that a major radiation release occurred. As noted in paragraph 33, it is many years since this policy was developed and there

may therefore be benefit in it being reviewed to ensure that it remains effective and relevant.

103 Having proposed a site, the applicant would also need to seek consent to proceed from the relevant Secretary of State under section 36 of the Electricity Act 1989 and make a submission in accordance with planning regulations. This may result in the Secretary of State calling a Public Inquiry.

104 The Phase Two Site Licensing element of HSE's proposed multi-stage assessment and licensing process could not complete until the overall planning submission process was complete.

105 The separation of the nuclear safety assessment process from the planning submission and public inquiry, by having parallel work streams, would allow more opportunity for public and other stakeholder comment.

Integrated nuclear regulatory assessment

106 We have discussed our proposals with the other UK nuclear regulators (the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA), and the Office for Civil Nuclear Security (OCNS)). While acknowledging that we all have separate regulatory responsibilities and processes, we all recognise the benefits of building upon our existing close working relationships to align these processes where possible and present applicants with joint regulatory positions.

107 To this end, we would seek to set up a joint project team with our fellow regulators to oversee and co-ordinate our separate regulatory processes relating to any applications received. We would continue to observe the terms and spirit of the existing Memoranda of Understanding between us, and ensure compatibility of our regulatory requirements and complementary assessment timescales.

Design Acceptance period of validity

108 During our stakeholder engagement, we have been asked to comment on the period of validity of any Design Acceptance certificate HSE might issue. We propose that any Design Acceptance would be valid for 10 years, subject to no significant new information arising during this period to undermine our confidence in the safety of the design. This is based upon the UK requirement for licensees to conduct periodic safety reviews of their existing nuclear facilities every 10 years and report them to HSE. HSE assesses the major periodic safety reviews and needs to be satisfied that the facility continues to meet its original design standards, has implemented all reasonably practicable modifications to close any gaps between those standards and modern standards, and has robust measures in place to manage any safety-related aging mechanisms in order to permit continued operation. If satisfied on all these aspects, HSE consents to continued operation of the facility for a further 10 years subject to continuing monitoring and inspections not revealing any new information that undermines the safety case.

109 If an applicant wished any Design Acceptance certificate to be renewed at the end of this 10-year period, we would require the applicant to review the safety case in the manner of a periodic safety review and report to HSE. We envisage that Design Acceptance renewal would be much less resource intensive than the original assessment, but some design improvements might be needed in order to gain renewal if these were found to be reasonably practicable at that time.

Requirements for legislative changes

110 We have not identified any fundamental legislative amendments that would be needed in order to implement our proposed multi-stage assessment and licensing process. The nuclear site licensing system would remain unchanged. Only the pre-licensing elements are expanded in the proposals discussed here and these requirements could adequately be detailed in guidance notes published by HSE.

Transfer of knowledge from vendor to licensee

111 The Nuclear Site Licence requires that the licensee is fully in control of all activities on its site, to understand the hazards of its activities and how to control them, and to be an intelligent customer. This requires the licensee to have suitably qualified, knowledgeable and experienced staff undertaking all activities that could affect safety on the site. We recognise that for many potential reactor designs, the expert knowledge would initially rest with the vendor and this could complicate nuclear site licensing. However, with the staged approach that we have proposed, we envisage that the Design Acceptance process could be vendor-led. This would allow the potential licensee sufficient time to build-up qualified and experienced staff and transfer knowledge to them from the vendor organisation.

112 By the time the applicant arrived at Phase Two, the Nuclear Site Licence application, we would expect this transfer to be advanced and the potential licensee organisation would be prepared to take appropriate control of all activities on the site once the licence was granted.

HSE regulation post-licensing

113 Following the granting of a Nuclear Site Licence, nuclear regulation would continue through tried and tested processes. Regulation through this phase would focus on procurement, construction, installation and commissioning issues and the licensee's development of its organisation to ensure it was at all times an intelligent customer with sufficient in-house expertise to manage and make informed decisions on issues affecting nuclear safety.

114 Through procurement, construction, installation and commissioning, HSE would use powers provided by the standard site licence conditions to apply a number of regulatory hold-points. Hold-points are agreed between the regulator and the licensee and are linked to defined activities requiring HSE's Consent before they may

proceed. Hold-points provide regular ‘review points’ during the project, and are vital for both licensee and regulator, as they give a formalised framework for resolving concerns before they become critical. It is anticipated that there might be fewer hold-points with the revised pre-licensing process we are proposing. Examples might be the construction and commissioning hold-points, which represent an agreed means of monitoring and controlling the project risks, and the final hold point, which is usually for routine operation of the plant and marks the end of construction and commissioning.

Conclusion

115 HSE has undertaken a thorough review of the potential role of pre-licensing assessments of candidate designs. We have considered how we might go about the appraisal of reactor designs in advance of specific proposals for new build for a particular site. In doing this we have been informed by past experience, international experience, and responses to our stakeholder engagement exercise.

116 In developing our proposed process we have endeavoured to build upon the proven UK nuclear regulatory process, ensure a rigorous examination of any new build proposals, and recognise the need for more public involvement than in the past and greater transparency of our regulatory processes.

117 We have concluded that a multi-stage assessment and licensing process should be considered. This would have two phases –Design Acceptance and Site Licensing.

118 We propose that Phase One is a four-step Design Acceptance process, which is site and operator neutral, and has a duration of something in the order of three years:

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.

119 Phase Two is HSE’s assessment to support issue of a Nuclear Site Licence and is site and operator specific. This involves assessment of the plant, the site and the operating organisation (who will become the licensee). If the applicant provides a detailed and high quality submission we would anticipate HSE’s Phase Two assessment would take approximately 6–12 months, assuming other permissions (for example, planning, Electricity Act) are forthcoming.

120 We have identified many factors which could influence this process, but overall we believe it would be rigorous, robust and transparent. This process would enable HSE to fulfil its responsibility for ensuring that any operators of nuclear licensed sites properly protect people and society from the nuclear hazards they control. However, to achieve this, additional resources will be required in NII.

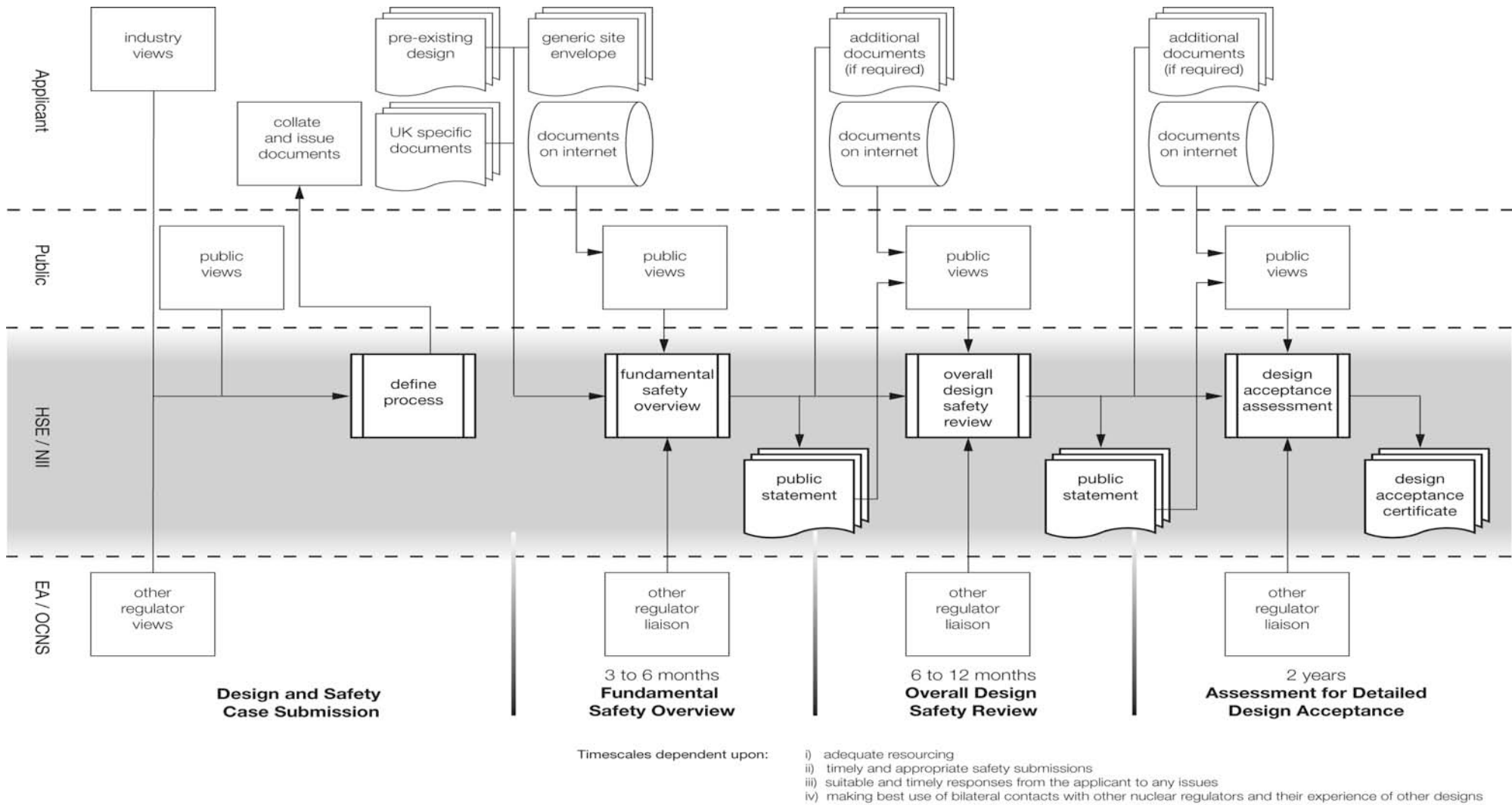


Figure 1 Pre-licensing – the proposed design certification process

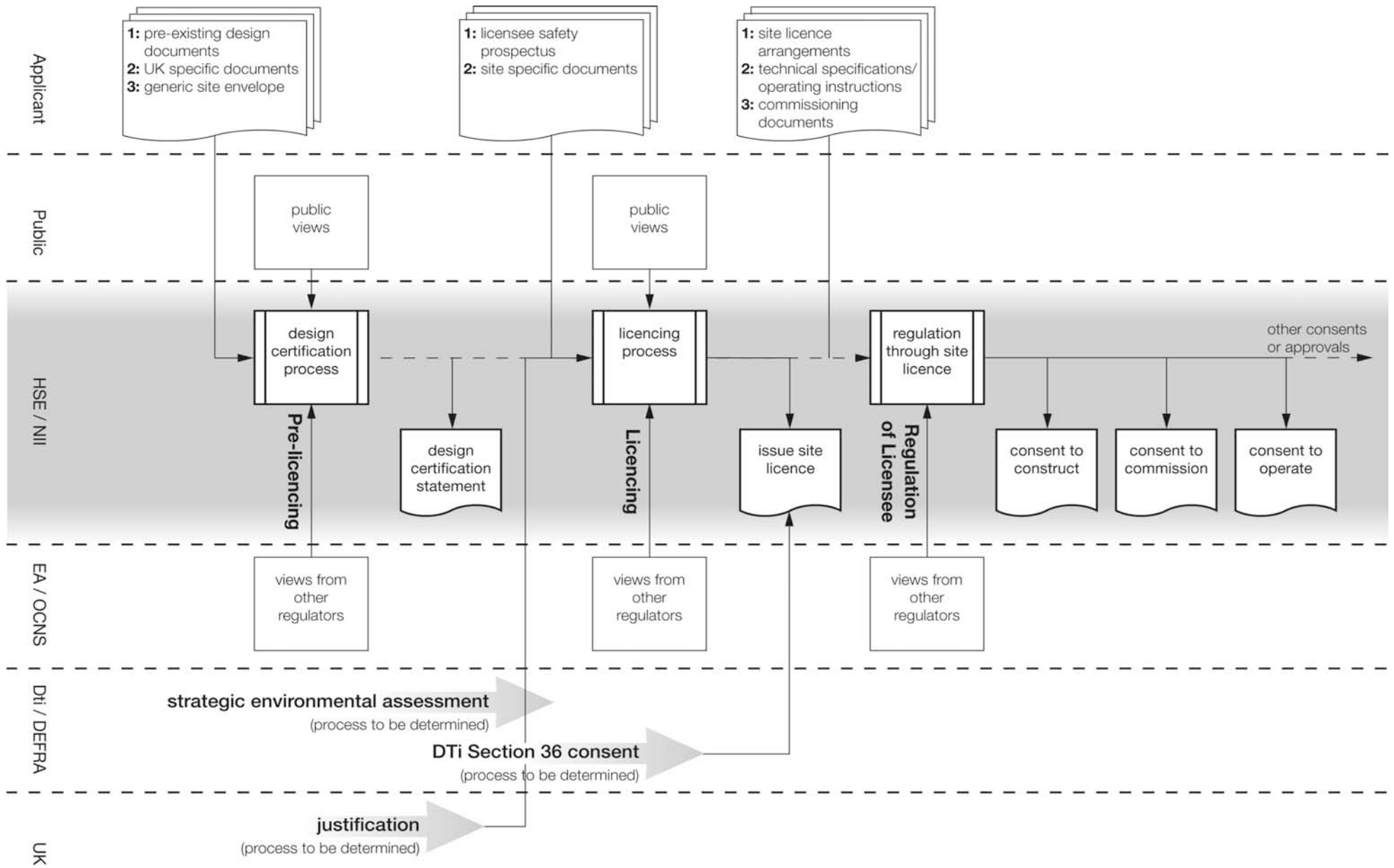


Figure 2 The overall licensing process

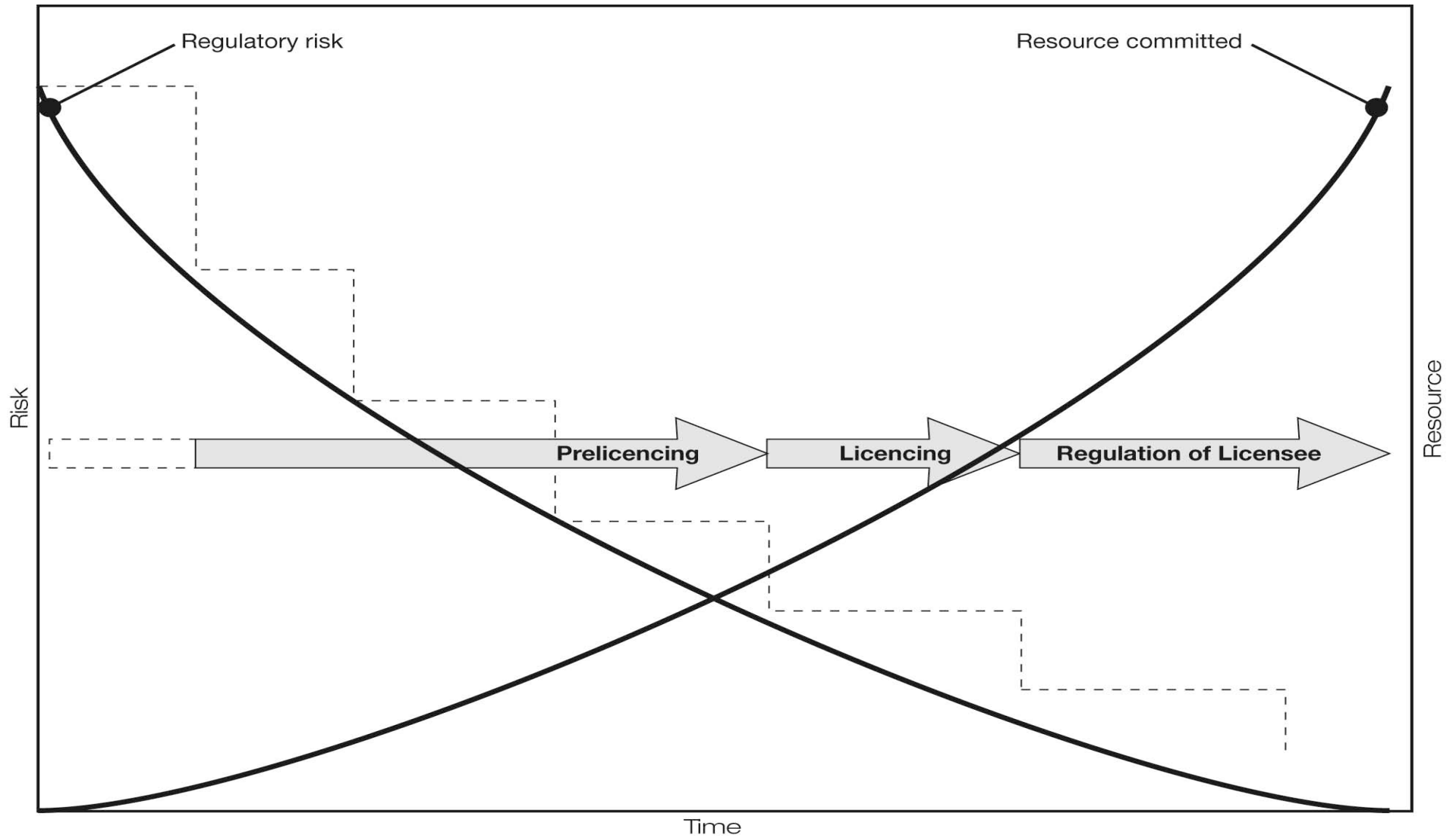


Figure 3 The relationship between licensing processes and regulatory risk. Regulatory risk reduces as the process delivers increasing confidence in requirements to meet UK legal expectations, and this also corresponds to increasing resource commitments.

ANNEX 3: GLOSSARY OF ABBREVIATIONS AND TECHNICAL TERMS

ACOP Approved Code of Practice under the HSW Act

acoustic enclosure a sound-proof enclosure used to contain noisy equipment so the noise in the general work area is at an acceptable level

AGR advanced gas-cooled reactors

ALARP as low as is reasonably practicable

alkaline a substance that can neutralise an acid, eg caustic soda

alternator machine to convert mechanical energy into electrical energy

AMN all measures necessary

AOGBO Application Outside Great Britain Order

API American Petroleum Institute

ASME American Society of Mechanical Engineers

BCGA British Compressed Gases Association

bcm billion cubic metres

biomass a generic term used to cover a number of biological sources including virgin crops/forestry, recycled crops/forestry and waste (eg sewage, refuse)

boil-off a proportion of liquefied gas stored at low temperature reverting to gas as heat is gained during transport

BS British Standard

BS EN European Normalised Standard adopted as a British Standard

BSI British Standards Institution

BSOR Borehole Sites and Operations Regulations 1995

BWEA British Wind Energy Association

BWR boiling water reactor

CA competent authority

CAA Civil Aviation Authority

CBM coal-bed methane

CCS carbon capture and storage

CCT cleaner coal technology

CEGB Central Electricity Generation Board

CEN European Committee for Standardization

CENELEC European Committee for Electrotechnical Standardization

CHIP Chemicals (Hazard Information and Packaging for Supply) Regulations 2002

CHP combined heat and power. The simultaneous generation of usable heat and power where the hot exhaust gases from the electricity-producing stage are used to heat water or generate steam

CO₂ carbon dioxide

COMAH Control of Major Accident Hazards Regulations 1999

commercial premises conducting a business other than those involving an industrial process (such as a factory). Examples include offices, hotels, and shopping malls

CORGI Council for Registered Gas Installers

CORGI registered gas operative who is, and whose company is, a registered installer with CORGI and therefore eligible under the Gas Safety (Installation and Use) Regulations 1998 to work on gas installations at domestic and commercial premises

COSHH Control of Substances Hazardous to Health Regulations 2002 (as amended)

CoRWM Committee on Radioactive Waste Management

DCR Offshore Installations and Wells (Design and Construction, etc) Regulations 1996

Design Certification an output from the proposed nuclear pre-licensing process

distributed power generation close to the consumer, either on-site generation or feeding into the distribution network and usually on a smaller scale than central power stations

domestic premises used for living and where no business is conducted, such as an individual house, but not a care home

DTI Department of Trade and Industry

EA Environment Agency

EC external combustion

ECBM enhanced coal-bed methane recovery

EESR Electrical Equipment (Safety) Regulations 1994

EIGA European Industrial Gases Association

electrolysis splitting chemical compounds into constituent elements by use of electricity

EOR enhanced oil recovery

EPR European pressurised reactor, a third-generation PWR design, as being built in Finland (Olkiluoto)

EPS Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996

ESQC Electricity Safety, Quality and Continuity Regulations 2002

ESR essential safety requirements

EU European Union

exothermic means to release heat. Chemical reactions that are exothermic can be difficult to control because the heat released increases the temperature of the reactants, increasing the reaction rate and releasing further heat in an escalating situation which may, if uncontrolled, lead to fire/explosion

external combustion equipment used to produce electricity (and heat) from engine working fluid that is maintained inside the system and heated by an external fuel source

fermentation the conversion of sugar to alcohol using yeast

fire suppressant fluid used to stop a fire from starting or spreading in the event of a fuel or oil leak

fuel cell a device similar to a battery that never becomes flat; when fed with hydrogen it continuously converts the chemical energy into electrical energy

gasification a process that takes carbon and reacts it with oxygen and steam to produce carbon monoxide and hydrogen

GASR Gas Appliances (Safety) Regulations 1995

gas turbine a rotary engine driven by a gas stream moving the blades

GSIUR Gas Safety (Installation and Use) Regulations 1998

GSMR Gas Safety (Management) Regulations 1996

HAZAN hazard analysis. The identification of undesired events that lead to materialisation of a hazard, the analysis of the mechanisms by which those undesired events could occur and usually the estimation of the extent, magnitude and likelihood of any harmful effects

HAZOP hazard and operability study. A study carried out by the application of guidewords to identify all deviations from design intent with undesirable effects for safety or operability. The outcome of the study is a list of actions for implementing further safety measures for otherwise managing risk

HSA Hazardous Substances Authority

HSC Health and Safety Commission

HSE Health and Safety Executive

HSW Act Health and Safety at Work etc Act 1974

hydrogen economy a scenario centred on releasing the energy stored in hydrogen either through direct combustion or through fuel cells in which hydrogen and related technologies play a significant part in powering devices

IAEA International Atomic Energy Agency

IC internal combustion

IEC International Electrotechnical Commission

IGCC integrated gasification combined cycle

IGEM Institution of Gas Engineers and Managers

IRRS Integrated Regulatory Review Service. IRRS is an external review carried out by IAEA to assist United Nation Member States to enhance the organisation and performance of their nuclear safety team

IRR99 Ionising Radiation Regulations 1999

ISO International Organization for Standardization

kW kilowatt (1000 watts)

kW_e the kW power output as distinct from the heat (or total) output

licence conditions framework of nuclear management goals to be achieved by licensees, but do not prescribe how these are to be achieved

licensee nuclear site licence holder

LNG liquefied natural gas

LPG liquefied petroleum gas: propane, butane or a commercial mixture of the two

LWR light water reactor

magnox magnesium/aluminium alloy

MAPD Major Accident Prevention Document

MCA Maritime and Coastguard Agency

metal alloys a combination of two or more elements, at least one of which is a metal, and where the resultant material has metallic properties different from those of its components.

microCHP unit producing up to 5 kW of power and a similar order of magnitude of heat

microturbine gas turbines producing up to 500 kW of power and a similar order of magnitude of heat

MoD Ministry of Defence

MoU Memorandum of Understanding

MW megawatt (1 000 000 watts)

NATS National Air Traffic Services

NDA Nuclear Decommissioning Authority

NFPA National Fire Protection Association

NGO non-Government organisation
NIA65 Nuclear Installations Act 1965
NI HSE's Nuclear Installations Inspectorate
NNC National Nuclear Corporation
NSD HSE's Nuclear Safety Directorate
NTS National Transmission System
NUSAC Nuclear Safety Advisory Committee

OCNS Office for Civil Nuclear Security
organic chemical chemical compound containing carbon and hydrogen
OSCR Offshore Installations (Safety Case) Regulations 2005

PAH polyaromatic hydrocarbons

PCSR pre-construction safety report

permissioning regime regulatory system involving licensing or approval by competent body before a particularly risky or hazardous activity can take place

pf pulverised fuel

photosynthesis a process by which green plants use the sun's energy to make carbohydrates

PHSR Planning (Hazardous Substances) Regulations 1992

POSR pre-operational safety report

pre-licensing regulatory and assessment processes carried out before a nuclear site licence is issued

pressure relief valve a valve or disc that opens to allow fluid to exit the system device when the pressure in a system is too high, thereby reducing the pressure

PSA probabilistic safety analysis

PSR Pipelines Safety Regulations 1996

purging a process of flushing through (using air, nitrogen or steam) a system to reduce its flammable or toxic contents to a safe level

PWR pressurised water reactor

pyrolysis a process that takes a biomass fuel and chemically decomposes it by heating in the absence of oxygen or any other reactant

R&D research and development

reciprocating internal combustion engine equipment used to produce electricity (and heat) where the combustion of the fuel takes place in a cylinder, producing expanding gases that are used directly to move a piston up and down

rpm revolutions per minute

SAPs Safety Assessment Principles

scCO₂ supercritical carbon dioxide

SEPA Scottish Environment Protection Agency

Seveso I the Council of the European Communities, Council Directive 82/501/EEC ('Seveso I') of 24 June 1982 on the major accident hazards of certain industrial activities *Official Journal of the European Communities* No L 230 of 5 August 1982

Seveso II the Council of the European Communities, Council Directive 96/82/EC ('Seveso II') of 9 December 1996 on the control of major accident hazards involving dangerous substances *Official Journal of the European Communities* No L 10/14 of 14 January 1997

SFAIRP so far as is reasonably practicable

SMR Supply of Machinery (Safety) Regulations 1992

syngas a mixture of hydrogen, carbon monoxide and other gaseous products produced by gasification and steam reforming of fuels

TAG technical assessment guide

town gas a mixture of methane, hydrogen and carbon monoxide produced from coke and used, via the mains gas distribution system, as a fuel until the 1950s

UGC underground coal gasification

UKOOA United Kingdom Offshore Operators' Association

UKOPA United Kingdom Onshore Pipeline Operators' Association

WEL workplace exposure limit

WENRA Western European Nuclear Regulators' Association

working fluid the fluid, contained inside an external combustion engine, that by heating and cooling cycles, drives the moving parts of the equipment

ANNEX 4: PRINCIPAL REFERENCES AND FURTHER READING

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ANNEX 5: STAKEHOLDER ENGAGEMENT

1 HSE engaged widely with a range of stakeholders while preparing this report. The consultation included:

- a workshop on nuclear energy matters (3 March 2006) to review regulatory strategy for licensing nuclear power stations followed by the publication of a nuclear discussion document on the HSE website for comment. Representatives of industry, trade unions, non-Governmental organisations (NGOs), Government departments and regulatory bodies were invited, together with academic experts; and
- a workshop on energy developments other than nuclear energy (9 May 2006) inviting a cross section of non-nuclear energy specialists to peer review HSE's contribution

2 In addition, an *Energy review* webpage was created on the HSE website (www.hse.gov.uk/consult/condocs/energyreview.htm) to keep all stakeholders alerted to HSE's approach to the review.

Nuclear energy

3 To develop its advice to the Government on the potential role of pre-licensing assessments, HSE reviewed its overall strategy for licensing new nuclear power stations. As part of this review, HSE held a well-attended stakeholder workshop on 3 March 2006, titled *The potential role of pre-licensing assessments of candidate designs in the event of new nuclear power station build*. Further information on this is included in Annex 2 paragraphs 34 to 38.

4 The objective of this event was to hear the views of organisations and individuals with a potential interest in the issues associated with pre-licensing assessments. The workshop was based on interactive discussions around a number of topic areas introduced by short presentations by staff from HSE's Nuclear Installations Inspectorate. Subsequent to the event, a discussion document setting out HSE's strategy for licensing a new reactor – including the role of 'pre-licensing' assessments and incorporating emerging issues from the workshop – was published on the HSE website and announced via an HSE press release.

5 The document invited comments from the public, between mid-March and 28 April 2006, on the regime's perceived robustness, clarity and consistency.

6 Meetings of NGOs were held on 11 April and 31 May, which brought together representatives from HSE, Greenpeace, Friends of the Earth, Nuclear Free Local Authorities, Stop Hinkley and the Welsh Anti-Nuclear Alliance. Issues of concern were discussed and HSE was able to provide clarification on its licensing strategy and the potential role of pre-licensing assessments.

7 All comments submitted were considered in developing policy on 'pre-licensing' and finalising the contribution to the report on nuclear energy issues.

Non-nuclear energy technologies

8 Non-nuclear energy specialists (with expertise relating to gas storage, renewable energy sources, distributed generation, cleaner coal technologies and carbon capture and storage) were invited to review HSE's contribution to the energy review at a workshop on 9 May 2006. The objective of this event was to identify any gaps or technical inaccuracies that needed to be dealt with in finalising the report. The workshop was followed up by correspondence between the authors of this report and the experts attending the workshop.

Further information

HSE priced and free publications are available by mail order from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA Tel: 01787 881165 Fax: 01787 313995 Website: www.hsebooks.co.uk (HSE priced publications are also available from bookshops and free leaflets can be downloaded from HSE's website: www.hse.gov.uk.)

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