Environment & Transportation Select Committee: 5 November 2013

Fracking Briefing Note: Potential Risks

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Introduction

1. The Environment & Transportation Select Committee has been asked to consider the motion 'in view of the potential environmental risks, this Council considers the controversial impact of fracking'. In order to support Members consideration of this topic, this briefing note summarises the findings of an independent review into the potential risks from hydraulic fracturing (fracking).

2. In 2012 the Government asked the Royal Society and the Royal Academy of Engineering to carry out an independent review to consider the major risks associated with hydraulic fracturing as a means to extract shale gas in the UK, including geological risks such as seismicity, and environmental risks such as groundwater contamination, and if these risks can be effectively managed.

3. The Royal Academy of Engineering and the Royal Society reviewed the scientific and engineering evidence relating to the technical aspects of the risks associated with hydraulic fracturing, and produced a report in June 2012 entitled 'Shale gas extraction in the UK: a review of hydraulic fracturing'. The full report (75 pages long) is available online:

   http://royalsociety.org/policy/projects/shale-gas-extraction/
   http://www.raeng.org.uk/news/publications/list/reports/Shale_Gas.pdf

4. The Executive Summary of this report is reproduced below, along with the recommendations arising from this review and the government response to those recommendations. Further extracts from the report follow, giving further detail on particular areas.

Executive Summary

5. The health, safety and environmental risks associated with hydraulic fracturing (often termed 'fracking') as a means to extract shale gas can be managed effectively in the UK as long as operational best practices are implemented and enforced through regulation.

6. Hydraulic fracturing is an established technology that has been used in the oil and gas industries for many decades. The UK has 60 years' experience of regulating onshore and offshore oil and gas industries.

7. Concerns have been raised about the risk of fractures propagating from shale formations to reach overlying aquifers. The available evidence indicates that this risk is very low provided that shale gas extraction takes place at depths of many hundreds of metres or several kilometres. Geological mechanisms constrain the distances that fractures may propagate vertically.

8. Even if communication with overlying aquifers were possible, suitable pressure conditions would still be necessary for contaminants to flow through fractures. More likely causes of possible environmental contamination include faulty wells, and leaks and spills associated with surface operations. Neither cause is unique to shale gas. Both are common to all oil and gas wells and extractive activities.

9. Ensuring well integrity must remain the highest priority to prevent contamination. The probability of well failure is low for a single well if it is designed, constructed and abandoned according to best practice. The UK's well examination scheme was set up so that the design of offshore wells could be reviewed by independent, specialist experts. This scheme must be made fit for purpose for onshore activities.

10. Effects of unforeseen leaks or spills can be mitigated by proper site construction and impermeable lining. Disclosure of the constituents of fracturing fluid is already mandatory in the UK. Ensuring, where possible, that chemical additives are non-hazardous would help to mitigate the impact of any leak or spill.

11. Concerns have also been raised about seismicity induced by hydraulic fracturing. Natural seismicity in the UK is low by world standards. On average, the UK experiences seismicity of magnitude 5 ML (felt by everyone nearby) every twenty years, and of magnitude 4 ML (felt by many people) every three to four years. The UK has lived with seismicity induced by coal mining activities or the settlement of abandoned mines for a long time. British Geological Survey records indicate that coal mining-related seismicity is generally of smaller magnitude than natural seismicity and no larger than 4 ML. Seismicity induced by hydraulic fracturing is likely to be of even smaller magnitude.

12. There is an emerging consensus that the magnitude of seismicity induced by hydraulic fracturing would be no greater than 3 ML (felt by few people and resulting in negligible, if any, surface impacts). Recent seismicity induced by hydraulic fracturing in the UK was of magnitude 2.3 ML and 1.5 ML (unlikely to be felt by anyone). The risk of seismicity induced by hydraulic fracturing can be reduced by traffic light monitoring systems that use real-time seismic monitoring so that operators can respond promptly.

13. Monitoring should be carried out before, during and after shale gas operations to inform risk assessments. Methane and other contaminants in groundwater should be monitored, as well as potential leakages of methane and other gases into the atmosphere. The geology of sites should be characterised and faults identified. Monitoring data should be submitted to the UK's regulators to manage potential hazards, inform local planning processes and address wider concerns. Monitoring of any potential leaks of methane would provide data to assess the carbon footprint of shale gas extraction.

14. The UK's goal based approach to regulation is to be commended, requiring operators to identify and assess risks in a way that fosters innovation and continuous improvement in risk management. The UK's health and safety regulators and environmental regulators should work together to develop guidelines specific to shale gas extraction to help operators carry out goal based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). Risk assessments should be submitted to the regulators for scrutiny and then enforced through monitoring activities and inspections.

15. It is mandatory for operators to report well failures, as well as other accidents and incidents to the UK's regulators. Mechanisms should be put in place so that reports can also be shared between operators to improve risk assessments and promote best practices across the industry.

16. An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations. Risks should be assessed across the entire lifecycle of shale gas extraction, including risks associated with the disposal of wastes and abandonment of wells. Seismic risks should also feature as part of the ERA.

17. Water requirements can be managed through integrated operational practices, such as recycling and reusing wastewaters where possible. Options for disposing of wastes should be planned from the outset. Should any onshore disposal wells be necessary in the UK, their construction, regulation and siting would need further consideration.

18. Wastewaters may contain Naturally Occurring Radioactive Material (NORM) that are present in shales at levels significantly lower than safe limits of exposure. These wastewaters are in need of careful management should NORM become more concentrated during waste treatment. NORM management is not unique to shale gas extraction. NORM is present in waste fluids from the conventional oil and gas industries, as well as in mining industries, such as coal and potash. Much work has been carried out globally on monitoring levels of radioactivity and handling NORMs in these industries.

19. Shale gas extraction in the UK is presently at a very small scale, involving only exploratory activities. Uncertainties can be addressed through robust monitoring systems and research activities identified in this report. There is greater uncertainty about the scale of production activities should a future shale gas industry develop nationwide. Attention must be paid to the way in which risks scale up.

20. Co-ordination of the numerous bodies with regulatory responsibilities for shale gas extraction must be maintained. Regulatory capacity may need to be increased.

21. Decisions are soon to be made about shale gas extraction continuing in the UK. The next round of issuing Petroleum Exploration and Development Licences is also pending. This report has not attempted to determine whether shale gas extraction should go ahead. This remains the responsibility of the Government. This report has analysed the technical aspects of the environmental, health and safety risks associated with shale gas extraction to inform decision making. Neither risks associated with the subsequent use of shale gas nor climate risks have been analysed.

22. Decision making would benefit from research into the climate risks associated with both the extraction and use of shale gas. Further benefit would also be derived from research into the public acceptability of all these risks in the context of the UK's energy, climate and economic policies.

Government Response

This Review made a number of recommendations to government. In December 2012 the Government published their response to these recommendations:

Recommendation 1
To detect groundwater contamination:
• The UK's environmental regulators should work with the British Geological Survey (BGS) to carry out comprehensive national baseline surveys of methane and other contaminants in groundwater.

The British Geological Survey (BGS) are working with the Environment Agency to establish a national baseline. DECC will work with the Environment Agency and SEPA to agree the scope of "other contaminants" that should be included.

• Operators should carry out site-specific monitoring of methane and other contaminants in groundwater before, during and after shale gas operations.

DECC considers this to be "good oilfield practice" and as such operators will be required to undertake site-specific monitoring and publish the results on their web sites. Where there is a groundwater risk, the environmental regulator will ensure the operator undertakes monitoring of methane and other contaminants in groundwater before, during shale gas operations and through to well abandonment.

• Arrangements for monitoring abandoned wells need to be developed. Funding of this monitoring and any remediation work needs further consideration.

Arrangements and financing for the monitoring and if necessary remediation of abandoned wells is the responsibility of the industry. DECC will work with UKOOG to put in place a robust scheme to ensure that abandoned wells remain safe and which satisfies, and is incorporated within site restoration and remediation agreements under the planning process.

For the Cuadrilla wells in Lancashire, the company has agreed to put in place specific measures, in advance of agreement on a wider scheme, to ensure effective monitoring and management of abandoned wells.

• The data collected by operators should be submitted to the appropriate regulator.

DECC will require operators to publish data on their websites.

Recommendation 2
To ensure well integrity:
• Guidelines should be clarified to ensure the independence of the well examiner from the operator.

Regulation 18 of the *Offshore Installations and Wells (Design and Construction etc) Regulations 1996 (DCR)* requires the well operator to set up a well examination scheme and appoint an independent competent person – the well examiner - to review the proposed and actual well operations to confirm they meet the well operator's policies and procedures, comply with DCR and follow good industry practice. Schemes of well examination must comply with the "*Guidelines for well operators on well examination*" and "*Guidelines for well operators on competence of well examiners*", published by Oil & Gas UK.

The requirement for the independence of the well examiner is crucial, and "independent" is further defined in DCR. This independence is usually achieved by well

examiners being from a separate company from the well operator. However, there are a few well operators who wish to use in-house examiners, and that option is legally open to them if they can fulfil the DCR requirements of an appropriate level of impartiality and independence from
any aspects of the well design/construction/operation. HSE provides guidance on this aspect, both in the Guidance on DCR (Booklet L84) and in SPC/TECH/OSD/43.

• Well designs should be reviewed by the well examiner from both a health and safety perspective and an environmental perspective.

Scrutiny by the well examiner to ensure well integrity from a safety perspective should in practice already serve to prevent the release of harmful material into the environment, as the goal setting requirements are to ensure there can be no unplanned escape of fluids from the well, so far as is reasonably practicable. However, there may be some aspects, such as a review of the appropriateness of fracking chemicals from an environmental perspective, which would be outside the strict legal scope of the well examination scheme, but which the well operator, (as the client of the well examiner) can nevertheless specify for the well examiner to cover. UKOOG is currently preparing guidance on good practice for shale gas operations, which recommends that the operator should ensure that the environmental implications should be assessed, either by the well examiner if he has appropriate skills, or by a separate contractor liaising with the well examiner.

• The well examiner should carry out onsite inspections as appropriate to ensure that wells are constructed according to the agreed design.

Well operators should have their own quality assurance processes to ensure wells are constructed to the agreed design. The separate work undertaken by well examiners depends on the scope of the well examination scheme devised by the well operator. Well examiners use documentary evidence of well integrity as the primary means of examination (as per the published DCR Regulation 18 Guidance) to obtain assurance that wells are designed and constructed properly and maintained adequately. It is not the practice that examination schemes need provide for physical examination of wells, unless reliance cannot be placed on the veracity of the documentary evidence.

However, for the purpose of increasing public confidence in the UK shale gas industry whilst it is in its infancy, UKOOG consider it appropriate for shale gas well operators to ask their well examiners to examine certain well integrity and fracturing operations in real time, especially during the early stages of a development, to provide a further level of independent assurance. Such periodic site visits should be made at the discretion of the examiner, in addition to assessing documentary evidence of well integrity, to observe and verify that such operations have been executed satisfactorily in accordance with the approved programme. The frequency and need for such site visits to shale gas operations would reasonably be expected to reduce with time.

• Operators should ensure that well integrity tests are carried out as appropriate, such as pressure tests and cement bond logs.

In order for well operators to ensure compliance with the goal setting requirements of DCR (which requires that wells should be "…*so constructed…..that so far as is reasonably practicable there can be no unplanned escape of fluids from the well*….") a range of appropriate well integrity tests will be required during the construction

phase, as detailed in standards and guidance such as the Oil & Gas UK “Well integrity guidelines”, which were drafted in consultation with HSE and DECC. The guidance being prepared by UKOOG will include reference to best practice specifically for shale gas wells.

• The results of well tests and the reports of well examinations should be submitted to the Department of Energy and Climate Change (DECC).

DECC already requires copies of digital logs to be lodged with the BGS, together with an ‘End of Well Report’. Cement bond logs and well examination reports will be added to the list of data specified. These data are available through DECC’s data release agents, and operators will be additionally required to make this data available upon request.
(http://og.decc.gov.uk/en/olgs/cms/data_maps/data_release/data_release.aspx).

Recommendation 3
To mitigate induced seismicity:
• BGS or other appropriate bodies should carry out national surveys to characterise stresses and identify faults in UK shales. Operators should carry out site-specific surveys to characterise and identify local stresses and faults.

BGS has already published regional memoirs which describe the tectonic history and faulting in many of the areas which are prospective for shale gas (http://www.bgs.ac.uk/research/ukgeology/subsurface.html). Structure contour and isopach maps, associated palaeogeographical maps, sections and correlation diagrams, are based on an analysis and interpretation of seismic, borehole and surface geological data, together with gravity and magnetic data, as well as other sources. These data are held at 10K & 50K scale in BGS’ DigMap data set. DECC has commissioned the BGS to complete a Bowland Shale regional mapping project, which will be published by DECC in early 2013. A further study is planned to map the Jurassic shale gas potential, and studies of the prospectivity of other shales will be considered after that report is published in late 2013.
DECC will require operators to understand the risks of hydraulic fracturing and to use these regional analyses, along with their own site-specific surveys, to characterise in-situ stress and identify faults that a well bore may penetrate.

• Seismicity should be monitored before, during and after hydraulic fracturing.

Before granting consent for shale gas operations which include hydraulic fracturing, DECC will require that a fracturing plan be submitted, for consideration with the well consent application. DECC will expect operators to demonstrate a full understanding of the risks of hydraulic fracturing. The detail should be proportionate to the risks, but in general, operators will need to evaluate the historical and background seismicity and the in situ stress regime; and delineate faults in the area of the proposed well to identify the risk of activating any fault by fracking. The fracturing plan should also include appropriate plans to monitor seismicity before, during and after the well operations conclude.

• Traffic light monitoring systems should be implemented and data fed back to well injection operations so that action can be taken to mitigate any induced seismicity.

DECC consent for shale gas hydraulic fracturing will only be granted when a "traffic-light" regime is in place so that operations can be quickly paused and data reviewed if unusual levels of seismic activity are observed. Operations will be halted, and immediate action taken to initiate flow-back to reduce pressure if seismic activity above a predefined level is observed. The predefined action levels will be chosen so as to minimise disturbance to local residents and so far as possible eliminate any risk of damage.

• DECC should consider how induced seismicity is to be regulated. Operators should share data with DECC and BGS to establish a national database of shale stress and fault properties so that suitable well locations can be identified.

DECC is working closely with the other regulators, BGS, industry experts and operators to establish controls for mitigating induced seismicity, with the development of robust traffic light arrangements forming an important component of this. BGS has compiled orientation and relative magnitudes of the contemporary in situ stress regime in the UK into a BGS stress GIS and database. BGS and operators will contribute to this national stress database (and the World Stress Map. (http://dcapp314.gfzpotsdam.de/pub/introduction/introduction_frame.html). However, the risk of induced seismicity cannot be fully eliminated through an understanding of regional/sub-regional stress, as this may not always reflect the true in-situ stress conditions at the wellbore and surrounding strata, but in using this public domain stress and fault data, operators can conduct site specific studies to evaluate the risk of induced seismicity.

Recommendation 4
To detect potential leakages of gas:
• Operators should monitor potential leakages of methane or other emissions to the atmosphere before, during and after shale gas operations.

The emphasis of this recommendation is on air quality issues, and the Environment Agency is undertaking a review of the environmental impacts of the industry, the regulations that apply and the controls that may be used to limit methane emissions to ensure that should the industry develop there will be a clear regulatory framework for these emissions. Techniques for use in the completion stage of well construction, to reduce the emissions of gases to air ("green completions") have been developed in the United States. The shale gas industry in the UK is in its infancy and green completion techniques are being developed based on industry best practice. DECC will ensure that UKOOG's guidance covers monitoring of potential leakages of gas and draws on the findings on the environmental regulators' review.

• The data collected by operators should be submitted to the appropriate regulator. These data could inform wider assessments, such as the carbon footprint of shale gas extraction.

Operators will post all carbon release data on their websites and summary data will be included in end of well reports. UKOOG's guidance will be amended to reflect the need for monitoring data to be collected by the operator and reported to the environmental regulator and DECC.

Recommendation 5
Water should be managed in an integrated way:

• Techniques and operational practices should be implemented to minimise water use and avoid abstracting water from supplies that may be under stress.

Water used for hydraulic fracturing may be sourced either by the operator directly, or indirectly through a licensed supplier. In either case, the licensing of water abstraction must take account of stresses caused by water demand, and this must be undertaken in consultation with the environmental regulator. Operators will be required to follow good oil field practice and adopt techniques that minimise water use - this will be reflected in UKOOG's guidance.

• Wastewater should be recycled and reused where possible.

This recommendation is supported by the regulators where it is acceptable within the current legislative framework. The Mining Waste Directive and the Environmental Permitting Regulations (EPR) require a review of options, prior to an environmental permit for disposal being granted by the regulator. This ascertains the most appropriate method for managing wastewater at each location.

• Options for treating and disposing of wastes should be planned from the outset. The construction, regulation and siting of any future onshore disposal wells need further investigation.

SUMMARY

This is already required as part of the EPR and is a requirement of the Mining Waste Directive. The use of disposal wells is not regarded as good practice by the environmental regulators or DECC.

Recommendation 6

To manage environmental risks:

• An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations, involving the participation of local communities at the earliest possible opportunity.

• The ERA should assess risks across the entire lifecycle of shale gas extraction, including the disposal of wastes and well abandonment. Seismic risks should also feature as part of the ERA.

ERAs are already required by legislation in certain contexts, although these may not address all aspects of the operations in question. For example, when applying for environmental permits, operators are required to submit mandatory environmental risk assessments to support their applications, which then form part of the public consultation process. The regulators concur that an overall ERA addressing all risks in appropriate detail would be desirable even where not specified by legislation, and DECC will expect all operators to carry out such an assessment as a matter of good practice. This assessment can then be mapped onto the assessments required by legislation, such as the Environmental Impact Assessment, where this is required following screening by the relevant planning authority.

DECC are consulting experts from Cranfield University to assist in the development of ERA guidance for shale gas activities as proposed by the academies, and to further address the scope requirements of the exploration and production phases.

The regulators support the engagement and participation of stakeholders, including local communities, at the earliest opportunity.

Recommendation 7
Best practice for risk management should be implemented:
• Operators should carry out goal based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). The UK's health and safety regulators and environmental regulators should work together to develop guidelines specific to shale gas extraction to help operators do so.

Risk assessment is central to a goal based regime and is required by UK health and safety legislation. Guidance on best practice for well integrity has been prepared by the Well Life Cycle Forum and published by Oil and Gas UK. This is being integrated into the guidance being prepared on behalf of UKOOG; this will bring together various standards, guidance and best practice. HSE/EA are both involved in this and do not intend to develop separate guidelines at this stage.

• Operators should ensure mechanisms are put in place to audit their risk management processes.

This is supported by HSE, as auditing of health and safety management systems is required by UK health and safety legislation.

• Risk assessments should be submitted to the regulators for scrutiny and then enforced through monitoring activities and inspections.

The intention of this recommendation is already achieved with respect to well integrity via the notification requirements of the Borehole Sites and Operations Regulations 1995 (BSOR). These require the well operator to submit details of well operations to HSE prior to their commencement, including the basis of the well design with respect to the geological strata and any hazards. These notifications are assessed by HSE's wells specialists, and issues likely to have an impact on well integrity can be identified and addressed by the operator. In addition, a variety of safety risk assessment information is included in the Health and Safety Document for the site, required by BSOR, These documents are a crucial part of an operator's approach to well integrity and health & safety on the site, and are valuable tools for HSE inspectors to use to devise intervention work and to assess well operator compliance. HSE will keep the potential implications of any extended surface operations (e.g. gas gathering stations, pipelines etc) under review should shale gas operations be scaled up following the early exploration phase.

When applying for environmental permits, operators are required to submit mandatory environmental risk assessments to support their applications. If an environmental permit is granted, the environmental regulator will develop a compliance assessment plan for each site to measure the operator's compliance and ensure that environmental risks are properly managed. This may include methods such as audits, site inspections, check monitoring and sampling and reviewing operator records and procedures.

• Mechanisms should be put in place to allow the reporting of well failures, as well as other accidents and incidents, between operators. The information collected should then be shared to improve risk assessments and promote best practices across the industry.

There is already a range of mechanisms for well operators to share lessons from wells incidents, ranging from the global OGP Wells Expert Group to the UK Well Life Cycle

Practises Forum and Oil & Gas UK and UKOOG. However, these fora have a much wider remit than just shale gas wells, so DECC will discuss this with the shale gas industry and ascertain the most appropriate routes to share best practice across shale gas operators.

Recommendation 8
The UK's regulators should determine their requirements to regulate a shale gas industry should it develop nationwide in the future. Skills gaps and relevant training should be identified. Additional resources may be necessary.

As noted in the report, there are greater uncertainties about the scale of production activities should a shale gas industry develop in future, and attention has to be paid to the way in which risks scale up. The regulators are already considering how to ensure the continued effectiveness in any such scenario of the current regulatory framework. The Environment Agency is conducting a review of the regulation relevant to its responsibilities, and the HSE likewise will keep under review the adequacy of its legislative framework.
The Shale Gas Strategy Group, chaired by DECC and attended by the regulators, considers that the regulatory skills already available are likely to meet the needs, but the issue of future regulatory resource has to be kept under review in the light of the evolving prospects for a future shale gas industry.

Recommendation 9
Co-ordination of the numerous bodies with regulatory responsibilities for shale gas extraction should be maintained. A single body should take the lead. Consideration should be given to:
• Clarity on roles and responsibilities.
• Mechanisms to support integrated ways of working.
• More formal mechanisms to share information.
• Joined-up engagement of local communities.
• Mechanisms to learn from operational and regulatory best practice internationally.

The Shale Gas Strategy Group, which includes the regulators, Defra and DCLG under DECC chairmanship, will continue to provide coordination on the development of shale gas policy and regulation across government departments, including these issues.

Recommendation 10
The Research Councils, especially the Natural Environment Research Council, the Engineering and Physical Sciences Research Council and the Economic and Social Research Council, should consider including shale gas extraction in their research programmes, and possibly a cross-Research Council programme. Priorities should include research into the public acceptability of the extraction and use of shale gas in the context of UK policies on climate change, energy and the wider economy.

The Research Councils are planning a workshop to consider the implications for UK research of the potential exploitation of unconventional hydrocarbon resources, including shale gas.

Further points from the above Review Report

General

- The UK has experience of hydraulic fracturing and directional drilling for non-shale gas applications. Over the last 30 years, more than 2,000 wells have been drilled onshore in the UK, approximately 200 of which have been hydraulically fractured to enhance recovery
- The problems experienced in the US derive from 'improper operational practices' e.g. contamination of groundwater supplies in Wyoming due to poorly constructed well casing and fracturing shallow shale formations (372m)
- In the US hydraulic fracturing is exempted from compliance with requirements to prevent water contamination and waste disposal restrictions
- In the UK, the environmental regulator has the power to demand the disclosure of the composition of fracturing fluids
- It is the decision of the local planning authority to decide who to consult. Health professionals should be consulted to advise on local health impacts whether directly or indirectly through the EA. The Health Protection Agency has established a working group of specialists to review the literature on the potential health impacts of shale gas extraction
- The Minerals Planning Authority should also consult the British Geological Survey for advice on induced seismicity and to help identify suitable locations for wells, and help MPAs oversee monitoring systems and other mitigation measures

Seismicity

- UK seismicity is low. The largest events are likely to be less than magnitude 5M, causing limited damage at the surface. Seismicity induced by coal mining is generally smaller than naturally occurring seismicity, perhaps no greater than magnitude 4M
- Seismicity induced by hydraulic fracturing is likely to be smaller than coal mining due to the greater depth at which shale gas is extracted. Magnitude 3M may be a realistic upper limit. If an event of magnitude 3M occurs at depths of 2-3km structural damage at the surface is unlikely

Average annual frequency of seismic events in the UK:

1.0M	100s each year	not felt except by a very few under especially favourable conditions
2.0M	25 each year	not felt except by a very few under especially favourable conditions
3.0M	3 each year	felt by few people at rest of in the upper floors of buildings, similar to the passing of a truck
4.0M	1 every 3-4 years	felt by many people, often up to tens of kilometres away, some dishes broken, pendulum clocks may stop

- Vibrations from a seismic event of magnitude 2.5m are broadly equivalent to the general traffic, industrial and other noise experienced daily
- since engineered hydraulic fracture are typically small, seismic events induced by hydraulic fracturing only produce high frequency radiated seismic waves, and so do not produce ground shaking that will damage buildings

- On the 1st April 2011 a 2.3M seismic event was recorded in the Blackpool area, and a further 1.5M event on 27the May 2011. Fracking was taking place nearby and as a result of these seismic incidents fracking was suspended and the events investigated. Both the DECC and operators reports attribute the two seismic events to the fracturing operations. The most likely cause was the transmission of injected fluid to a nearby pre stressed fault
- Microseismic events are a routine feature of hydraulic fracturing due to the propagation of engineered fractures. Larger seismic events are generally rare but can be induced by hydraulic fracturing in the presence of a pre stressed fault
- Controlling the pressure in a well is an important measure to mitigate induced seismicity
- More research is needed to better understand the precise relationship between well pressure and seismicity induced in shales
- Tests carried out after the 2.3M event revealed deformation of the well casing. DECC should consider the conditions under which repeat pressure tests and or cement bond logs would be required to provide evidence about whether well integrity had been compromised following unexpected levels of induced seismicity, reviewed by an independent well examiner
- The BGS or other appropriate bodies should carry out national surveys to characterise stresses and identify faults in UK shales. Operators should also carry out site specific surveys to characterise local stresses and identify nearby faults
- Operators can draw on well understood tools used in the oil and gas and mining industries to assess the orientation and slip tendency of faults
- Traffic light monitoring systems are best practice. Data are fed back to operations so that action can be taken to mitigate induced seismicity. Such systems should be implemented in the UK for shale gas extraction.
- Waste fluids can be disposed of through injection into disposal wells. Pressure in disposal wells can build up over time inducing seismicity. Magnitude tends to be greater than that induced during fracturing (though it does not typically exceed 5M) and could be mitigated
- Operators should carry out a seismic risk assessment as part of their environmental risk assessments
- The DECC should consult with Mineral Planning Authorities to consider the adequacy of underground injection of fluids regulations regarding induced seismicity and possible conditions of environmental permits or local planning permission

Fracture Propagation and Groundwater

- Operators have an incentive to carefully monitor fracture propagations, as uncontrolled fracture growth is uneconomic
- Microseismic monitoring can be used, and fracturing can be monitored in three dimensions and in real time. These events typically have a magnitude of less than -1.5M
- The environmental regulator is responsible for deciding whether fracking poses a contamination risk to groundwater and if an environmental permit is necessary to set limits on the activity to manage the risk to an acceptable level
- At present, the environmental regulator does not permit fracturing below freshwater aquifers
- Microseismic data from the US shows that fractures created by hydraulic fracturing are very unlikely to propagate vertically more than one kilometre.
- The very unlikely event of fractures propagating all the way to overlying aquifers would provide a route for fracture fluids to flow. However it is very difficult to

conceive of how this might occur given the UK's shale gas hydrogeological environments. Upward flow of fluids from the zone of shale gas extraction to overlying aquifers via fractures in the intervening strata is highly unlikely
- Shale gas is likely to be extracted at depths of many hundreds of metres or even several kilometres

Surface Spills
- Surface spills of fracturing fluid may pose a greater contamination risk than hydraulic fracturing itself. The impact of any spills can be mitigated using established best practice. In the UK, installing impermeable site lining is typically a condition of local planning permission

Water Requirements
- An operator is required to seek an abstraction permit from the environmental regulator if more than 20m^3 of water is to be abstracted per day from surface or groundwater bodies. If water is instead sourced from a mains supply, the water company will need to ensure it can still meet the conditions of the abstraction permit that it will already be operating under
- Estimates indicate that the amount needed to operate a hydraulically fractured shale gas well for a decade may be equivalent to the amount needed to water a golf course for a month, to run a 1,000 MW coal fired power plant for 12 hours, and the amount lost to leaks in United Utilities region in north west England every hour
- Operators could consult water utilities companies to schedule operations to avoid periods when water supplies are more likely to be under stress
- It is also possible to use waterless fracturing fluids, which could reduce the toxicity of waste products

Waste Water
- Approximately 25% to 75% of the injected fracturing fluid flows back to the surface when the well is depressurised
- In the USA wastewaters have historically been stored in containment ponds. Open storage ponds are not permitted in the UK. Wastewaters in this country are stored in closed metal tanks before being treated. Leaks or spills can be managed. This hazard is not unique to shale gas extraction but common to many industrial processes.
- Recycling wastewater where possible would reduce the volumes of wastewater in need of disposal, although it could concentrate contaminants and thereby complicate disposal
- The transport of wastewaters is carried out by road haulage companies licensed by the UK's health and safety regulators with experience of transporting hazardous substances
- Disposal wells may be necessary
- Wastewaters are regulated. Operators are required to formulate waste management plans that identify how wastes are to be minimised, treated recovered and disposed of. This includes identifying environmental and health impacts and measures to address them
- Radioactive elements can be dissolved in wastewaters. This is normally at levels significantly lower than safe limits of exposure. However wastewaters need careful management should Naturally Occurring Radioactive Material (NORM) become more concentrated during treatment

- An environmental permit is required for disposing of NORM wastes that exceed 'out of scope' concentrations

Other Waste Products

- Venting and flaring of methane and other emissions are controlled through conditions of Petroleum Exploration and Development Licences
- Local Authorities are responsible to inspect sites for odour and noise associated with the venting or flaring of gas. Local authorities also have a statutory duty to monitor emissions to ensure they do not breach local air quality standards
- 'Green completion technologies' are used in the USA to capture and then sell any methane and other gases emitted from flowback water. The EPA has issued regulations making this mandatory for hydraulic fracturing in the USA from 2015 onwards. No such requirements exist in the UK. Consideration should be given to their use especially for any future production activities in the UK

Well Construction

- Some of the leaky wells in a Canadian study had only a single casing or were left uncased except the section from the surface to just below the acquifer
- In the UK, standard practice is to have three strings of casing with at least two passing through and thereby isolating any freshwater zones
- The UK's well examination scheme is highly valuable, allowing well designs to be reviewed by specialised experts
- Regulations require the design and construction of offshore and onshore wells to be examined by an 'independent and competent person'. The examiner can ask for results of well integrity tests and can raise any health and safety concerns with the operator
- Guidelines should be clarified to ensure the well examiner is an employee of a separate company
- Regulations state that wells should be constructed so that 'as far as is reasonably practicable there can be no unplanned escape of fluids from the well and risks to the health and safety of persons from it or anything in it, or in strata to which it is connected, are as low as is reasonably practicable'.
- There is currently no legislative requirement for pressure tests of Cement Bond Logs to be carried out

Methane contamination

- A US study concluded there was evidence of methane contamination of certain aquifers overlying a shale formation in Pennsylvania associated with hydraulic fracturing. This conclusion has been contested. No evidence of contamination with fracturing fluids was found in the study.
- It is important to understand the baseline of naturally occurring methane to understand impacts of activity. The British Geological Survey is establishing a baseline survey of methane in groundwater in areas likely to be investigated for shale gas extraction in the UK (Wessex and weald basins 4th priority area for this)

Risk Assessments

- An Environmental Impact Assessment may be required.
- An Environmental Risk Assessment is best practice and should be mandatory for all shale gas operations, assisted by guidelines specific to shale gas extraction.
- ERA assesses not just the impacts of hazards but also their likelihood. This would help prioritise risks.

- The assessment should cover the entire lifecycle and seismic risks.
- Guidelines should help operators carry out ERAs according to ALARP principle.
- Operators should allow stakeholders to participate in the framing of risk and evaluating different means of managing them

Future Developments

- Existing UK regulation contains the necessary elements to manage the risks associated with small scale activities
- A single body should take leadership to ensure co-ordination of the numerous central and devolved bodies with responsibilities for regulating shale gas extraction in the UK
- Research programmes are recommended before shale gas extraction commences on any significant scale
- Research should also investigate what makes a regulator trustworthy as concerns tend to focus less on a particular technology per se and more on how the technology is governed in real world circumstances