Public Health England

Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction

Draft for Comment

About Public Health England

Public Health England's mission is to protect and improve the nation's health and to address inequalities through working with national and local government, the NHS, industry and the voluntary and community sector. PHE is an operationally autonomous executive agency of the Department of Health.

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Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction: Draft for Comment

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This report from the PHE Centre for Radiation, Chemical and Environmental Hazards reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

EXECUTIVE SUMMARY

Public Health England (PHE) is an executive agency of the Department of Health and provides a nationwide, integrated public health service, supporting people to make healthier choices. PHE aims to ensure that everyone is protected from threats to their health from infectious disease and environmental hazards. PHE has operational autonomy and is free to publish or speak on issues relating to the nation's health and wellbeing in order to set out professional, scientific and objective judgements of the evidence base.

Shale gas extraction is at an early exploratory stage in the UK with very limited drilling having actually occurred. Indeed, fracturing operations to test for shale gas extraction in the UK have only occurred at one site to date and that was halted following minor earth tremors. It is likely that further exploratory drilling will commence soon. Despite such limited activity to date, shale gas extraction raises concerns with the general public. Well publicised reports from other countries, most notably the United States of America, suggest that drilling and extraction of shale gas using hydraulic fracturing, commonly referred to as fracking, has the potential to adversely impact the environment and human health.

In response to emerging public concern regarding the process of fracking for shale gas extraction, and requests for advice from national and local agencies, PHE's Centre for Radiation, Chemical and Environmental Hazards (CRCE) established a working group in May 2012 to undertake an initial review of the public health impact of direct emissions of chemicals and radioactive material from the extraction of shale gas. Other considerations such as climate change and greenhouse gas emissions, sustainable use of water resources, nuisance issues such as noise and odours, traffic (apart from vehicle exhaust emissions), occupational health, and visual impact, are not considered in this review. Similarly, the review does not consider the socio-economic benefits or impacts of shale gas extraction.

This review focuses on the potential public health impacts of exposures to chemical and radiological pollutants as a result of shale gas extraction in the UK based on the examination of literature and data from countries which already have commercial scale shale gas extraction operations. Caution is required when extrapolating experiences in other countries to the UK since the mode of operation, underlying geology and regulatory environment are likely to be different.

The currently available evidence indicates that the potential risks to public health from exposure to the emissions associated with shale gas extraction are low if the operations are properly run and regulated. Most evidence suggests that contamination of groundwater, if it occurs, is most likely to be caused by leakage through the vertical borehole. Contamination of groundwater from the underground fracking process itself (i.e. the fracturing of the shale) is unlikely. However, surface spills, of fracking fluids or waste water, may affect groundwater; and emissions to air also have the potential to impact on health.

Where potential risks have been identified in the literature, the reported problems are typically a result of operational failure and a poor regulatory environment. Therefore, good on-site management and appropriate regulation of all aspects including exploratory drilling, gas capture, use and storage of fracking fluid, and post operations decommissioning are essential to minimise the risk to the environment and public health. In the UK, shale gas developers and operators will be required, through the planning and environmental permitting processes, to satisfy the relevant regulators that their proposals and operations will minimise the potential for pollution and risks to public health. PHE and other public health bodies will provide support by responding to requests to assess the potential impact on health in specific circumstances.

The report makes a number of recommendations:

- Public Health England needs to continue to work with regulators to ensure all aspects of shale gas extraction and related activities are properly risk assessed as part of the planning and permitting process.
- Baseline environmental monitoring is needed to facilitate the assessment of the impact of shale gas extraction on the environment and public health. There should also be consideration of the development of emission inventories as part of the regulatory regime.
- Effective environmental monitoring in the vicinity of shale gas extraction sites is needed throughout the lifetime of development, production and post-production.
- It is important to ensure that broader public health and socioeconomic impacts such as increased traffic, impacts on local infrastructure and worker migration are considered.
- Chemicals used in fracking fluid will be publically disclosed and risk assessed prior to use. It is useful to note that any potential risk to public health and the environment from fracking chemicals will be dependent on the route of exposure, total amount and concentration, and eventual fate of any such chemicals. It is expected that these aspects will be considered as part of the regulatory environmental permitting process.
- The type and composition of the gas extracted is likely to vary depending on the underlying geology and this necessitates each site to be assessed on a case by case basis.
- Evidence from the USA suggests that the maintenance of well integrity, including post operations, and appropriate storage and management of fracking fluids and wastes are important factors in controlling risks and appropriate regulatory control is needed.
- Characterisation of potentially mobilised natural contaminants is needed including naturally occurring radioactive materials (NORM) and dissolved minerals.

CONTENTS

1 INTRODUCTION

Shale gas is a natural gas found in shale, a fine grained sedimentary rock. The extraction or production of natural gas from shale differs from conventional forms of gas and oil extraction from defined reservoirs or traps where the hydrocarbon (the gas or oil) has migrated from the source rock. In the case of shale gas, the extraction is considered unconventional as the gas is obtained directly from the source rock itself.

Shale gas is typically methane but may contain small quantities of other gases including hydrogen sulphide, carbon dioxide, nitrogen, and other hydrocarbons. The composition of shale gas is dependent on the geological formation as well as the temperature and pressure that the formation has been subjected to over time.

To extract shale gas, the usual approach involves the drilling of a number of wells in different directions (called directional drilling) from a single well pad to target potential reserves of gas, which is illustrated below.

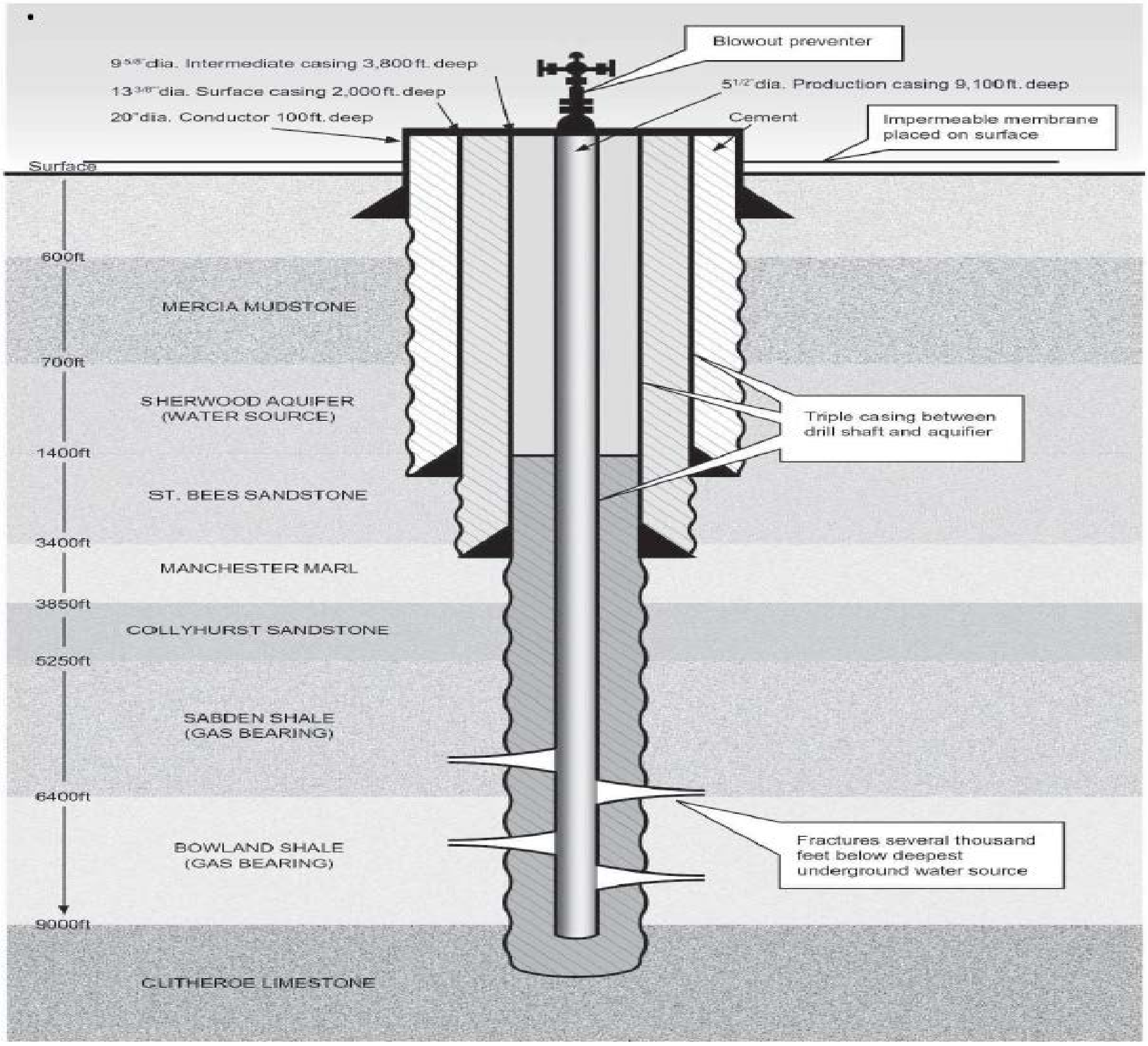

Figure 1: Bowland Shale Well Schematic (Not to scale)

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenergy/795/795we09.htm

The initial step is the drilling of a vertical bore hole to a prescribed depth. Once the final vertical depth has been reached the core of the bore hole is encased with cement to prevent contamination of the surrounding rock. Horizontal directional drilling of the rock may take place in different directions and these horizontal drillings can extend for thousands of feet from the original vertical bore hole. In order to extract gas from the shale, a process called hydraulic fracturing, also known as fracking is used. This is a technique in which water is pumped into the rock at extremely high pressures to create small fractures or cracks in the shale. These fractures allow the gas to escape from the shale and flow into the well bore where it is carried back to the surface for capture and processing. Once the fractures are created, small particles, typically grains of sand, are used to keep the fractures open (called proppants or propping agents). Chemicals are often added to the water to improve the efficiency of the fracturing process and these include friction reducers, surfactants, gelling agents, scale inhibitors, acids, corrosion inhibitors, antibacterial agents, and clay stabilisers. This water mixture is termed fracking fluid and the fracturing process can involve the use of large quantities of fracking fluid, with estimates ranging from 9,000 to 29,000 m^3 (9-29 million litres) water per well, which is usually made up on site from water supplied from the local water company or abstracted from a local water course or aquifer.

A significant proportion of the fracking fluid pumped into the borehole is lost below ground; however some fluid, known as flowback water, returns to the surface. The flowback water is returned to the surface as a high pressure mixture of natural gas (predominantly methane), other gases, water, brine, solids, minerals and hydrocarbons. It may also contain low levels of naturally occurring radioactive materials (NORM). Estimates of the fraction of flowback water recovered varies by geologic formation and typically ranges from 10% to 70% of the injected fracking fluid (Groundwater Protection Council and ALL Consulting 2009, US EPA 2011). The volume of flowback water depends on the properties of the shale, the fracturing design and the type of fracking fluid used (King G.E 2012).

The shale gases are separated out while the flowback water and hydrocarbons are stored on-site in storage tanks. The hydrocarbon liquid is called condensate and can be transported to refineries for further processing.

Drilling and extracting shale gas, whether for exploratory or commercial purposes, broadly involves five separate stages:

1. Developing a well pad and drilling and constructing a wellbore to the target shale formation. This can involve horizontal drilling in a number of directions.
2. Hydraulic fracturing (fracking) of the shale to extract the gas.
3. The capture and processing of the returning gas (during the exploratory phase this may involve flaring or venting of the gas).
4. The storage, treatment and disposal of flow-back water and other wastes.
5. Decommissioning of the bore-hole and well pad.

Gas exploration techniques, using directional drilling and fracking, are not new and have been used across the oil and gas industry (including in the UK) for many decades. As the technology has improved over time so has the ability to exploit shale gas economically.

It has been proposed that the exploitation of shale gas resources has the potential to provide economic and environmental benefits (US EPA 2012); however, this remains subject to debate. Experience from other countries, especially the USA, suggests that shale gas has the potential to be a widely distributed resource that can be relatively cheaply produced and may lessen dependence on imported oil and gas which has important energy security benefits. The development of shale gas in the United States has been very rapid. In 2001, shale gas was less than 2% of total U.S. natural gas production; in 2011 it approached 30% (Secretary of Energy Advisory Board 2011). The U.S. Energy Information Administration is predicting a continuing expansion of shale gas production in the future and projects that shale gas will account for 46% of domestic production by 2035 (US EIA 2011).

The scale of future shale gas production in the UK is uncertain. The British Geology Survey (BGS) undertook a simple estimate of the production potential based on an analogy with the Barnett Shale formation in Texas. This suggested that shale beds in the UK could yield some 150 billion cubic metres of gas which roughly approximates to around two years of UK energy demand (Diaper M 2012). However, this estimate was not based on a detailed analysis of all UK shale beds and there is little information on the amount of gas that may be technically recoverable in shale beds in the UK. Further work continues to assess the UK's shale gas resources.

Across Europe there is considerable interest in developing shale gas resources, with Poland, Germany, the Netherlands, Spain, Romania, Lithuania, Denmark, Sweden and Hungary all expressing an interest. Poland has the most advanced shale gas programme to date having undertaken fracking at six test wells. (AEA Technology 2012).

The impacts of shale and other forms of unconventional gas extraction have been subject to a number of independent reviews in the UK including by The Tyndall Centre for Climate Change Research (Broderick J et al, 2011) , a House of Commons Committee (House of Commons 2011) and most recently the Royal Society and Royal Academy of Engineering (Royal Society 2012). All three reviews concluded that there are potential health and environmental impacts associated with shale gas extraction, with the main risks associated with contamination of the environment with fracking fluids or natural contaminants mobilised as a result of the fracturing process. The need for appropriate regulation of all aspects of shale gas extraction was also recognised, with key recommendations including the need for risk assessment of chemicals used in fracking fluids and ensuring good design and integrity of wells. Environmental monitoring before, during and after fracking and improved analytical techniques to detect the chemicals in fracking fluid and flowback water were also recommended.

Outside of the UK, there have been a number of notable reviews and studies for the European Commission covering environmental, health and climate change impacts (AEA Technology 2012, European Parliament 2011), a comprehensive health impact assessment in the USA (Colorado School of Public Health 2011) and a detailed examination of the potential public health impacts in New Brunswick, Canada (Office of the Chief Medical Officer of Health, New Brunswick 2012). The United States Environmental Protection Agency (US EPA) is currently conducting a detailed study into the potential impacts of hydraulic fracturing on drinking water and ground water, which is due for publication in 2014 (US EPA 2012).

As with any industrial process, shale gas extraction must be undertaken in a manner that reduces the impact on the environment and consequently minimises the risk to human health. In the USA, public concern about shale gas extraction has grown as production has increased and typically falls into five areas:

1. Pollution of drinking water supplies.
2. Air pollution.

3 Community disruption during shale gas production.
4 Supply and safe storage of chemicals used in fracking.
5 Cumulative adverse impact on communities.

Similar concerns have been raised about shale gas extraction in the UK in advance of commercial drilling. In addition to the areas identified above, other potential concerns may include:

6. Radionuclides dissolved in water, including NORM and radon, which can be released underground from rocks and become dissolved in the fracking fluid.
7. Radioactive tracers if they are used to monitor the fracking process (IAEA 2003) .
8. Contamination arising from waste water.

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2 SCOPE AND PROCEDURE

A search of the published or peer reviewed scientific literature until December 2012 was undertaken. Searches for peer reviewed papers were carried out over the following databases: Toxnet, Scopus, Pubmed, Science Direct. Other literature was identified from internet searches and key Government websites in the UK, European Union, USA and Canada. The titles and keywords of relevant papers were scanned to select the best words/phrases to refine the literature search. Search terms used included shale gas, fracking fluid, hydraulic fracturing, fracking, fracturing, unconventional gas, NORM, radon, frack & radioactive.

Contacts were made in the UK with a range of stakeholders including the Environment Agency, British Geological Survey and the Department of Energy and Climate Change (DECC). Links were also established with international agencies, including US EPA to help identify on-going work, data, reports, conference proceedings etc.

This initial report is focused exclusively on the direct health impact of releases into the environment due to emissions from the production of shale gas (and some liquid hydrocarbons) from shale formations with hydraulic fracturing in either vertical or horizontal wells. It is recognised that community concerns can extend to broader issues (e.g. socio-economic impacts, visual amenity, noise) and there is a wider public debate about the longer-term impact of shale gas extraction on greenhouse gas emissions and their impact on climate change. It is also recognised that some of the observations and recommendations in this report could be extended to other oil and gas operations. However, this initial assessment has focussed solely on issues related to local emissions arising from shale gas extraction and any potential direct health impacts.

For the purposes of this report, the following areas have been considered:

- Air pollution including from stationary on-site sources, and radon.
- Water pollution including use of fracking fluids, flowback water, presence of natural substances e.g. heavy metals and NORM, and the risk to water courses or aquifers.

- Land / waste issues including disposal and treatment of waste water, muds, etc.

The following areas are outside the scope of this initial report:

- Occupational health issues.
- Climate change and greenhouse gas emissions
- Water usage, water sustainability issues.
- Energy policy and security.
- Nuisance issues including, noise and odours.
- Seismicity.
- The wider impacts of shale gas extraction on local employment and the local economy.
- Detailed consideration of the longer term impact of shale gas extraction on climate change.

3 REGULATORY ENVIRONMENT

In the UK strict regulatory requirements governing onshore oil and gas exploration already exist and shale gas extraction will be regulated within this framework. Currently, DECC issues operators with licences to undertake exploratory drilling. Such exploration also requires planning permission from the local planning authority. In terms of the regulation of drilling activities operators will require an environmental permit from the appropriate environmental regulator (i.e. the Environment Agency in England, Natural Resources Wales, the Scottish Environmental Protection Agency and the Northern Ireland Environment Agency (NIEA)). In England shale gas developments could require several permits under the Environmental Permitting (England and Wales) Regulations 2010 which incorporate the requirements of a number of different pieces of legislation, such as the Water Framework Directive, the Groundwater Daughter Directive and the Radioactive Substances Act 1993[*]. An environmental permit would cover areas such as water abstraction, groundwater activity, waste water discharge consents, Naturally Occurring Radioactive Material (NORM) and the handling and disposal of mining wastes. Exposure to radioactivity due to shale gas extraction will have to be assessed as part of this regulatory regime and radiation doses to members of the public will need to be demonstrated to be kept well below the statutory limit of 1 mSv per year.

The Health and Safety Executive (HSE) will oversee working practices under the Health and Safety at Work Act 1974. The HSE is also responsible for regulating public safety within, and in the direct vicinity of the well (borehole) work activities. In addition, the HSE is involved in ensuring well casing integrity and quality. An industry body, the UK Onshore Operators Group (UKOOG) has produced guidelines for operators on well integrity and hydraulic fracturing for the exploration and appraisal phase (UKOOG 2013).

[*] Similar provisions exist in other parts of the UK

A number of commentators in the USA and Canada have expressed concern that public health agencies are not engaged with industry and policy makers over the regulation of shale gas extraction/exploitation (Goldstein B.D et al, 2012, New York Health Professionals 2011). This should not be an issue in the UK as public health bodies play an important role in both planning and permitting of industry by acting as independent consultees in both these processes. At present, public health professionals in Public Health England and Public Health Wales are routinely asked to comment on environmental permit applications and we would therefore expect public health bodies to be consulted on permits associated with shale gas developments. Similarly we would expect local public health professionals to play an active role during planning applications. Both processes will help ensure that public health agencies participate in and contribute to initiatives around the regulation of shale gas.

4 AIR QUALITY

4.1 Introduction

A review of the peer reviewed scientific literature and discussions with key agencies did not identify any UK data (published or unpublished) on emissions to air associated with fracking or shale gas extraction. There is one site that has been operating in the UK since 1996 with vertical hydraulic fracturing to release gas in sandstone formations at Elswick, Lancashire but no data on air emissions associated with this site appear to have been published. Similarly no air quality data have been obtained for more recent exploratory drilling for shale gas at Preese Hall, Lancashire.

The potential impacts on air quality have been assessed by the European Commission (AEA Technology 2012) with much of its review focussing on data from the USA. A number of studies and data suggest that shale gas extraction operations can be a source of air pollution, both primary pollutants such as oxides of nitrogen (NO_x) and particulate matter (PM) and the precursors of secondary pollutants such as ozone (O_3). Emission inventories relating to commercial shale gas extraction and related activities in Texas (Barnett and Haynesville shales), Arkansas and Pennsylvania have been examined.

4.2 Evidence on key pollutants and their sources

Published evidence from the USA and other countries suggests a potentially wide variety of different sources of air pollutants from shale gas extraction and related activities. Sources can include:

- Direct emissions from engines powering the drilling and fracking operations and compressors used to capture and transport the gas on site. Pollutants can include particulate matter (PM), carbon monoxide (CO), NO_x including nitrogen dioxide (NO_2).
- Emissions from the venting of condensate and oil tanks on site. Pollutants can include a range of volatile organic compounds (VOCs).
- Emissions from gas capture and flaring. Pollutants may include methane, NO_x and other gases associated with the flaring of the gas as well as PM.

- Fugitive emissions associated with leaks from pumps, flanges, valves, pipe connectors etc. Pollutants can include methane and other gases.

However, on a site by site basis, these emissions are relatively small, intermittent and certainly not unique to shale gas extraction and related activities. Emissions of a number of air pollutants associated with shale gas extraction and related activities can lead to the formation of secondary pollutants such as ozone (O_3), which is generated by photochemical reactions involving nitrogen oxides and volatile organic compounds in the presence of sunlight. Emissions from shale gas extraction operations may also lead to the formation of secondary particles. However, many pollutants associated with shale gas extraction are also produced in significant quantities from other sources, for example industry and transport, and from atmospheric processes and therefore there will be an existing background level of both primary and secondary pollution.

Zielinska et al analysed air pollutants associated with shale gas extraction and related activities in Barnett Shale, in Texas (Zelinska et al, 2010). Air quality canister sampling identified 70 individual volatile organic compounds (VOCs) in the vicinity of the compressor station, functioning well, condensate tanks and during associated transport operations on and off-site. The most abundant non-methane VOCs were ethane, propane, butane, and pentanes, which accounted for approximately 90% of total emissions. The key source appeared to be malfunctioning condensate tanks. Emissions from these condensate tanks were localised and reported concentrations in ambient air decreased significantly downwind from the tanks. Higher molecular weight hydrocarbons were less common and mostly associated with vehicle exhaust emissions and combined natural gas and condensate tank emissions and then small gasoline engines.

Emission data from shale gas extraction and related activities in Fayetteville Shale (Arkansas) in 2008 shows that natural gas production (including shale gas) were significant sources of many common air pollutants (Dept. of Environmental Quality, Arkansas 2011). The inventory indicated that it was not just emissions from the gas capture and hydraulic fracturing process that were identified but that emissions from engines powering compressors, drilling rigs and the hydraulic fracturing pumps were also significant. Emissions from compressor engines were the main sources of NO_x, CO, PM_{10}, sulphur dioxide (SO_2) and carbon dioxide (CO_2).

Data from these emission inventories also demonstrate that the composition of the shale gas will vary due to differences in shale beds. The type and range of non-methane VOCs measured in gas collected from Fayetteville Shale differed markedly from that reported for Barnett Shale. While gas produced from the Barnett Shale was VOC rich, Fayetteville Shale gas contained relatively low amounts of VOCs.

VOC emissions from shale gas drilling were reported as part of a hydrocarbon emissions study in the Denver-Julesburg Fossil Fuel Basin, Colorado (Pétron, G et al 2012) . This study involved the collection of daily air samples at the National Oceanic and Atmospheric Administration Boulder Atmospheric Observatory, which were then analysed for methane and non-methane VOCs. Other sources in the area included other oil and gas operations, a landfill site, a wastewater treatment plant and motor vehicle emissions. Oil and gas activities including shale gas extraction and related activities were strongly associated with alkane and benzene levels in the atmosphere. Key sources of emissions appeared to be flashing from condensate tanks (where gases dissolved in the liquid condensate are released due to decreasing atmospheric pressure) and venting of oil or gas wells.

Emitted VOCs and oxides of nitrogen are important precursors for ozone formation and the potential impacts of shale gas extraction and related activities on regional ozone levels has been demonstrated for the Haynesville Shale which covers Northeast Texas and Northwest Louisiana (Kemball-Cook S et al 2010, Kemball-Cook S et al 2012). Based on well production data from state regulatory agencies and experience from other developments (especially the nearby Barnett Shale), projections of future Haynesville Shale natural gas production were derived for 2009-2020 for three scenarios corresponding to limited, moderate, and aggressive development. These estimates indicated that projected emissions of ozone precursors, in this case NO_x, from the exploration and development phase could have a sufficiently large impact on O_3 levels in Northeast Texas and Northwest Louisiana to result in these areas failing to meet the relevant health standard/guidelines for ozone. It was also suggested that emissions from the Haynesville Shale could affect other regions due to long-distance O_3 transport.

An assessment (Colborn T et al 2011) of the potential impact of shale gas extraction and related activities on local air quality in the USA and noted the importance of emissions of VOCs and exhaust emissions from on-site generators. The assessment concluded that air quality monitoring for individual VOCs and O_3 must be a requirement of shale gas regulation. They also stressed the need for monitoring to start before drilling to establish baseline levels against which impacts can be measured.

A review for the European Commission examined potential emissions to air during the various stages of shale gas development and production. The review concluded that the type and source of emissions varied with the different phases of well development (AEA Technology 2012). The importance of diesel emissions from drilling equipment and associated traffic was highlighted. The evidence indicated that while impacts from individual sites were likely to be minor, the cumulative impact from multiple sites could potentially be more significant especially in terms of impacts on regional air quality such as elevated levels of ozone. As a result, this preliminary assessment for the European Community concluded that the potential risks to human health and the environment from releases to air across all phases of development was high.

Shale gas is predominantly methane which is a flammable gas and explosive in air at concentrations between 5 and 15% by volume. While methane can present a risk to health in confined spaces where high concentrations build up and displace oxygen from the air, emissions of methane from shale gas extraction and related activities are not expected to be an immediate threat to public health. Evidence from the USA suggests that methane releases to air from deep shale measures tend to be via failures in well infrastructure and inefficient gas capture rather than directly from gas migrating through overlying rock (UP EPA 2012) . Emissions of methane should be well controlled through gas capture and/or flaring and venting.

4.3 Regulation and monitoring

Regulations covering shale gas extraction and related activities apply in some states of the USA, including monitoring requirements for classical air pollutants such as: CO; lead (Pb); nitrogen dioxide (NO_2); particulate matter (typically $PM_{2.5}$); SO_2 and O_3 precursors. Monitoring requirements also include monitoring for organic air pollutants such as a range of VOCs including BTEX (benzene, toluene, ethylbenzene, xylenes), formaldehyde, hexane, and 2,2,4-

trimethylpentane. Methane emissions are also often monitored as part of climate change assessments.

In April 2012 the US EPA announced new and updated air pollution regulations for natural gas facilities including shale gas extraction and related activities. These regulations cover both the facility and other elements of oil and natural gas development including emissions from on-site equipment such as processing plants, storage tanks and compressors as well as from the gas wells themselves. The key tool in these regulations is the use of pollution abatement equipment to control and reduce emissions from the gases, liquids and other substances that flow from the well (Weinhold, 2012). The aim is to ensure efficient capture of the gas produced and thereby reduce emissions. Completing a well installation with such equipment is called “green completion”. Since much of the captured gas includes products with a market value such as propane and butane there is also a financial incentive. Flaring of gas is not encouraged as this can create combustion pollutants such as CO, NO_x, PM and CO_2. Reductions in emissions from on-site equipment and additional reporting requirements are included within the regulations. The USEPA estimate that the green completion process and other associated changes will cut VOC emissions by 95%.

In addition to these new regulations, a number of USA States have started to develop emission inventories and region-wide monitoring programmes to quantify better the extent and significance of emissions from unconventional gas extraction. Pennsylvania, which includes the Marcellus Shale, is currently collating an emission inventory for 2011. This inventory requires reporting for a range of air pollutants including CO, NO_x, PM_{10}, $PM_{2.5}$, SO_2 and VOCs. Additional reporting is also required for benzene, ethylbenzene, formaldehyde, N-hexane, toluene and 2,2,4-trimethylpentane. Other states have already published their inventories including Arkansas and Texas. In New Brunswick, Canada, the Chief Medical Officer recommended that the Province establish monitoring networks for ambient air in local areas expected to have shale gas production (Office of the Chief Medical Officer of Health, New Brunswick 2012) . It was recommended that these monitoring networks should be able to detect both local and regional impacts of emissions and provide baseline monitoring as well as monitoring during the lifetime of the development and post-production.

Experience from the USA demonstrates the need to collect a comprehensive dataset on emissions from shale gas production activities. This should include the development of emission inventories and regular monitoring of ambient air quality around shale gas extraction sites and their associated activities. Without such data, it would be difficult to undertake a detailed assessment of the impact of emissions on human health. The variety of emission sources also emphasises the need for appropriate regulatory control in the UK to ensure that all emissions associated with shale gas exploration and exploitation, both direct and fugitive, are controlled and assessed. This should include assessment of emissions as part of local air quality management strategies. However, it is important to understand that in the UK background levels of air pollution vary from place to place. In some areas, specific sources, such as pollutants emitted by vehicles near roads, will dominate while in others regional, national or even international sources can be important contributors to existing levels of pollution. Therefore, emissions from shale gas will need to be put into the context of the existing background level of ambient air pollution.

4.4 Human health risk assessment

Up to December 2012, there has only been one detailed human health assessment published in the peer reviewed literature examining the impact of air emissions from shale gas operations. This study (McKenzie L.M,et al 2012), is part of a larger health impact assessment undertaken by a research group based at the Colorado School of Public Health (Colorado School of Public Health 2011) . The research looked at the impact on a local community of a large shale gas development potentially incorporating up to 200 individual gas wells. A range of issues were examined from the impact of emissions to air, land and water, noise and visual impact, transportation to and from the site, the health profile of the local community, economic benefits and broader social issues such as the impact of the influx of workers on the infrastructure of the local community.

McKenzie et al used a risk assessment methodology which considers cancer and non-cancer endpoints separately to assess the potential health impact of air emissions from shale gas extraction and related activities. It should be noted that the risk assessment methodology used in this study is not recommended for use in the UK, as discussed below.

Cumulative non-cancer hazards were estimated by McKenzie et al using a hazard index (HI) approach, where the ratio of estimated exposure is compared with a health based guideline value (in this case reference concentrations, RfCs) to produce Hazard Quotients (HQ) for each chemical, which are summed to produce a HI. If the resultant HI is greater than 1, there is an indication of the potential for health concern. The HI assumes cumulative (i.e. additive) effects of chemicals; it can be calculated assuming additivity across all chemicals and effects, or a HI for a specific endpoint can be estimated by only including substances which exert this effect. Chosen non-cancer endpoints included neurological, respiratory, haematological and developmental effects.

Chronic HIs were calculated for a full 30 year project duration, and subchronic HIs using subchronic RfCs, where available, for a 20 month exposure during the well development phase. In respect of cancer, lifetime risks were estimated by multiplying the estimated exposure, over a 30 year project lifespan, by the inhalation risk derived by the US EPA or Californian EPA for each chemical and these results were summed to estimate the cumulative cancer risk.

The risk estimates from the HI approach identified well development and completion (about 20 months exposure to hydrocarbons) as posing the highest risk (HI of 5 based on the 95% upper confidence limit (UCL) of the mean concentration, and a HI of 0.4 based on the median exposure) for the nearby population, resident within half a mile. The main health endpoint of concern was neurological effects with trimethylbenzenes the main causative agents, but haematological, respiratory and developmental effects all contributed to the combined HI. Estimated cancer risks and chronic non-cancer hazard indices were greater for residents living within half a mile of the nearest well pads, with 1 in 10^5 cancer risk and a HI of 1 (based on 95% UCL of the mean concentrations), compared to a 6 in 10^6 cancer risk and a HI of 0.4 in those living over half a mile from the nearest pads. Benzene and ethylbenzene were the main contributors to cancer risks but overall the concentrations of both chemicals were similar to those found more generally in urban areas in the USA. The key finding was that the calculated potential for risks for sub-chronic non-cancer endpoints (20 month exposure) were elevated for those residents living within half a mile of the gas wells during well completion.

In the UK, risk assessments are usually based on the most sensitive health endpoint, rather than undertaking evaluations for cancer and non-cancer effects separately. Also, the approach used for cancer risk assessment in the USA is not recommended for use in the UK by the UK advisory Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (COC) if the risk values used are derived from animal data (COC 2012) . Nevertheless, the paper highlights that emissions to air from activities associated with the drilling and development of gas wells can be locally significant and, like other sources of air pollution, may present a potential risk to health. The paper suggests that the potential risks from subchronic exposure are of most concern, especially among residents closest to the well pad. The key exposure appears to be chemicals emitted during well development and completion activities. It is also clear that emissions to air come from a variety of sources associated with the drilling and operation of a well pad and are not simply associated with the extraction of gas from the well itself. It is unlikely that the results are directly applicable to other extraction sites either in the USA or other countries since local factors such as type and duration of drilling, local meteorology and topography etc. will vary from well site to well site. The researchers are clear that this is a preliminary study and the results show a need for further research. Prevention strategies to minimise exposures during well completion activities are recommended.

The paper has a number of limitations and uncertainties, many of which are acknowledged by the authors. These include:

- Small sample size and the limited amount of data on emissions around well completion sites.
- Further work is needed to profile emissions during the stages of gas well development.
- Non-methane pollutant emissions appear to vary substantially by field type, number of well heads, completion process, and controls in place. This makes application of the results to other shale gas extraction sites very difficult.
- A limited number of volatile organic compounds was explored, but not other primary or secondary pollutants (e.g. aldehydes, diesel exhaust, ozone, PM, etc.).
- Other pollutant sources need further assessment. The existing background level of pollution needs further assessment as it is not clear how much extra pollution was caused by the shale gas extraction and related activities.
- The impact of local meteorology and topography means that the results are not easily applicable to other areas and other extraction sites.

4.5 Summary

There are a large number of different sources of gaseous emissions during shale gas extraction and related activities including those directly relating to gas capturing and flaring and those associated with infrastructure such as diesel engines, storage tanks, vehicles, etc. Emissions will vary between sites due to differences in the underlying geology and the thermal maturity of the shale. Emissions from specific sites will vary temporally, with different pollutants emitted during different phases of well development and operations, and will vary spatially because operations may be across many individual wells each at different stages of development. Local topography and meteorological conditions will also add to the difficulties in accurately assessing dispersion and potential exposure.

Published studies in the USA have begun to assess the potential impact of shale gas extraction and related activities on local air quality through emissions inventories, although the level and type of emissions during all stages of shale gas development and production are not fully characterised. Evidence is beginning to emerge to better quantify emissions during well development and completion, and evaluate the type of VOCs emitted directly during gas venting, from engine and vehicle exhausts or fugitively from leaks from gas pipe works etc. The available evidence indicates that a large number of VOCs can be emitted, depending on the source and level of VOCs in the shale gas itself, and that these emissions can impact on local air quality.

Shale gas extraction and related activities can be major sources of classical air pollutants such as PM, NO_x, SO_2, and benzene and also of O_3 via its formation from primary emissions. The available evidence suggests that while emissions from individual well pads are low and unlikely to have an impact on local air quality, the cumulative impact of a number of well pads may be locally and regionally quite significant. In the USA, shale gas fields are strongly associated with ground-level ozone pollution due to the emission of ozone precursors such as VOCs. Multiple sites can also be a significant source of particulate matter, especially diesel particulates from the compressors, engines and traffic associated with production.

It is clear from experience in the USA that the level and type of emissions to air during all stages of shale gas development and production are not fully characterised. Emissions vary widely depending on the phase of development, the geology, local topography and meteorology and the types of activities and equipment on-site. Such variability makes direct application to the UK situation impossible but shows that control of emissions from shale gas extraction and related activities will be of central importance. Comprehensive air monitoring and associated assessments of health risks will be required in the UK to inform regulation of each phase of the operation.

4.6 Gaps in knowledge and recommendations for further work

Evidence suggests that the composition of shale gas will vary according to geology and as a result each shale bed will need a detailed risk assessment. Comprehensive air quality monitoring is needed to enable exposure assessment and should be a critical part of any risk assessment process. The air quality monitoring will allow the development of detailed emission inventories which need to consider the stage and phase of well development as evidence indicates that this will influence the emission profile.

The available evidence suggests that the impact of individual wells on air quality is likely to be low and particular emphasis should be on assessing the cumulative impacts of emissions on air quality from multiple drilling sites. Air monitoring should reflect this and consider not only local air quality impacts but also the potential for regional air quality effects due to pollutants such as ground-level O_3, PM and NO_x/NO_2. Any future regulatory regime should clarify responsibilities in terms of local air quality assessments. It is recommended that public health professionals work with regulators to ensure air monitoring around such sites will provide information necessary to assess the potential for any impact on public health.

UK risk assessment will ideally apply an agreed methodology for assessing health effects of exposures to mixtures of VOCs and other pollutants from the various phases of shale gas extraction and related activities. This should include assessment of chronic exposures over the lifetime of the well pad and also subchronic exposure over various durations corresponding to particular stages of the process e.g. drilling, fracturing, extraction and production.

5 RADON

5.1 Introduction

Some radionuclides, including members of the uranium and thorium radioactive decay chains, are naturally present in soils and rocks. Certain soils and rocks, including granites, limestones and shales, are associated with relatively high levels of these radionuclides and members of their radioactive decay chains; within the UK the activity concentration of uranium-238 (^{238}U) in soil ranges from 2 to 330 Bq kg^{-1} (UNSCEAR 2010).

Radon-222 (^{222}Rn), a noble gas which is a member of the ^{238}U radioactive decay chain, is released to air from most of the land surface of the Earth. The release of radon from rocks and soils is determined largely by the types of minerals in which uranium occur. Since radon is a gas, it has much greater mobility than other radionuclides within the uranium radioactive decay chain, which are fixed in the solid matrix in rocks and soils. Radon can more easily leave the rocks and soils by escaping into fractures and openings in rocks and into the pore spaces between grains of soil. If radon is able to move easily in the pore space, then it can travel a great distance before it undergoes radioactive decay. Radon migration to the surface is controlled by the transmission characteristics of rocks and soils and the nature of carrier fluids, including ground water.

Where radon escapes to open ground, the activity concentration of radon in air is generally low, typically a few Bq m^{-3} (Wrixon A 1988). Where radon is drawn into buildings, due to indoor pressure differential and the containment caused by the building, concentrations of radon can be significantly higher, in some cases many thousands of Bq m^{-3}. In order to control exposure to radon, measured indoor air concentrations are compared against action levels. Where an action level is exceeded, remediation is encouraged.

Exposure to natural sources of radiation contributes approximately 84% of the average annual dose of radiation to a member of the UK population (Watson et al 2005) . This exposure comes from both intakes of radionuclides from air and within food, as well as external exposure to radionuclides present in the ground and from space. Exposure to indoor radon is generally the most significant source of radiation exposure to the UK population, contributing approximately 50% of the total dose (Watson et al 2005) .

A review of the literature, and discussions with key agencies, did not identify any UK-specific data on radon associated with shale gas extraction and related activities. Some measurements of radon relating to shale gas extraction activities have been reported in the USA. These are discussed in the relevant section.

5.2 Radon released to air from the earth's surface

Radon is released to air from near-surface soil and rock structures through the local natural network of voids, cracks etc. Small scale disturbances to this network might lead to short-term changes in the rate of release but would not lead to significant or sustained changes in the long term release rate of radon to atmosphere.

The substantial depth at which fracking takes place means that it is difficult to envisage how it might cause the physical changes that would be necessary to result in a significant short or long term change in the release of radon from the earth's surface.

Boreholes for shale gas exploration might pass through rock layers that have naturally elevated radon concentrations. Provided the integrity of the impervious casings of these well bores is maintained, radon is unlikely to intrude into the well bore from surrounding rock.

5.3 Radon in natural gas

Radon is present in natural gas such as shale gas. Levels vary because each well lies on different geology and has different depth. Before natural gas reaches consumers, it is generally blended and may spend time in storage or in transit from the originating well. Typical levels of radon in natural gas have been reviewed (Dixon D 2001). For typical domestic rates of gas usage with an average UK radon level of about 200 Bq m^{-3}, the estimated individual annual dose from the use of natural gas for UK residents is estimated at 4 μSv (microsieverts), which is extremely small.

The Marcellus shale deposit in the USA has been the subject of many studies. Johnson (1973) gives an average radon level in US natural gas production of 1370 Bq m^{-3} (37 pCi l^{-1}) (Johnson R 1973). A model employed by Resnikoff (Resnikoff M 2012) showed that at the wellhead radon levels in the shale gas can reach 1365 – 95,300 Bq m^{-3} (36.9 - 2576 pCi l^{-1}). The study estimated that, depending on the gas treatment, processing as well as transport length, the radon concentrations in the shale or natural gas delivered to customers may range up to 72,000 Bq m^{-3}, resulting in indoor radon concentrations of the order of 20 Bq m^{-3}, similar to the average level of radon in indoor air of UK homes. These figures are based on estimated wellhead radon concentrations which are, in turn, derived from models of emanation from radium concentrations. The models do not appear to reflect any dilution of the shale-derived natural gas with natural gas from other sources and assume continuous on-going exposure at the peak rate. Resnikoff also states that conventional wellhead concentrations were lower during a survey of the USA in 1973 than estimates made in his report for wellhead concentrations associated with fracking.

The US Geological Service (Rowan and Kraemer, 2012) reported measurements of ^{222}Rn between the wellhead and gas-water separator stages of 11 fracking wells in the US, including some at Marcellus shale sites. The observed values range from 37 to 2,923 Bq m^{-3}.

If the natural gas delivery point were to be close to the extraction point with a short transit time, radon present in the natural gas would have little time to decay; the half-life of radon is 3.8 days. No data are yet available on radon concentrations in shale gas from UK at the wellhead. The UK has an extensive national gas transmission system (National Grid 2012).

There is, therefore, the potential for radon gas to be present in natural gas extracted from UK shale, as is the case with existing natural gas supplies. The radon concentration in natural gas delivered to consumers would depend on the original radon gas concentration modified by transit times, storage, dilution (with other natural gas) and the effects of any processing or blending of the natural gas. Using the existing UK model (Rowan and Kraemer, 2012), it is estimated that natural gas containing radon at the upper end of the range (2,923 Bq m^{-3}) reported by the USGS would give individual exposures of the order of 60 µSv y^{-1}.

Unwanted flammable gases arising from natural gas wells are sometimes flared off. Radon may be present in such gas flows. In these circumstances, any radon released would be rapidly dispersed in the atmosphere and would be very unlikely to lead to any significant public radiation exposure. Doses from this potential pathway could be assessed using information about the radon concentration in the gas, flaring practices and considering local atmospheric dispersion.

5.4 Radon in water

Radon and radium are relatively soluble in water and although there is a risk associated with ingestion, most of the radiation dose associated with radon in water supplies comes from radon in air in locations where degassing occurs. The highest radon concentrations tend to be found in ground water which has been in contact with crystalline rocks but radon levels in water do vary between wells on the same geology. Surveys carried out in the UK have found some private water supplies have radon activity concentrations approaching 1000 Bq l^{-1} (BGS & Dept. of Environment, Transport and the Regions 2000), far higher than those found in public water supplies. Where high radon concentrations are found in private water supplies, reduction measures are advised. In these cases, radon that de-gases from the water supply often makes a significant contribution to overall exposure by adding to the total indoor airborne radon concentrations.

If fracking were to create new vertical fractures, or extensions to existing fractures, these might provide a pathway for contaminants from the shale layer into overlying strata. Models have indicated that normal advection times from depth to near surface aquifers can be decreased by fracturing. Current evidence (Royal Society 2012) suggests that most fractures only extend a few hundred metres upwards with the chance of a fracture extending more than 600 metres being exceptionally low. Reports from the USA have indicated that radon in water from wells close to hydraulic fracturing activity is greater than elsewhere (Otto J 1992). However, the source of the elevated levels has not been clearly identified and there is natural variation in radon levels in water drawn from different sources. Myers (Myers T 2012) examined the issue of radon from shale gas and concluded that, based on the depth of target shales, any radon released is likely to decay before it reaches any ground water supply via advection.

Since the expectation in the UK is that fracking will occur at some considerable depth (typically more than a thousand metres below the surface) then the impact of any radon released into groundwater would be minimal.

5.5 Radon in flowback water

Radon can be present in flowback water due to its solubility. The amount of radon will also depend on the amount of its parent, radium-226 (^{226}Ra). The average radon content in soil gas, measured in USA, is about 7,400 to 74,000 Bq m^{-3} (200 to 2,000 pCi l^{-1}) and may exceed 37,000 000 Bq m^{-3} (100,000 pCi l^{-1}) (Otto J 1992, Myers T 2012, Gundersen L 1993). No measurements were found specifically for radon in flowback water from shale gas operations. In the USA, reported gross alpha levels within fracking flowback water were in the range 0.8 to 700 Bq l^{-1} (New York State Dept. of Environmental Conservation 2011). Samples of flowback water from the Preese Hall exploratory site in UK showed gross alpha concentrations in the range 10 to 200 Bq l^{-1} (EA 2012). Both reports identify the presence of radium-226, the radioactive precursor of radon (see section 6). It is likely that radon will be present in flowback water.

Radon de-gassing from the flowback water will be facilitated by the turbulence and high temperature of the fluid. This may lead to elevated radon levels in the proximity of the wellhead, but further studies would be required to measure the radon released during the extraction process. Since this is likely to lead to only very localised increases in airborne concentrations of radon, it is only likely to be of potential relevance to on-site occupational exposures.

5.6 Summary

It is considered unlikely that shale gas extraction and related activities would lead to any significant increase in public exposure from outdoor radon levels or indoor levels in nearby homes.

In common with other sources of natural gas, there may be potential for radiation exposure from radon in natural gas obtained from shale gas extraction.

The depth of shale gas extraction zones is much greater than the depth from which private water supplies are extracted from the ground. It is unlikely that radon released from shale gas zones would reach water supplies originating from the ground.

Radon may be present in flowback water used in shale gas fracturing and may be released to atmosphere. Radon released in this manner is not likely to lead to significant public radiation exposure.

5.7 Gaps in knowledge and recommendations for further work

It is considered very unlikely that shale gas activities would have any significant effect on radon levels in homes, radon levels vary between homes and higher than average levels occur even away from radon prone areas. Thus, it may be that in areas where shale gas extraction takes place, some householders may choose to monitor for radon and may attribute any elevated levels to local shale gas extraction. It would be useful to have an evidence base to refer to in the event of such inquiries.

Radon is present in low concentrations in conventionally extracted natural gas and has been assessed for its radiological significance. Shale gas extraction presents a further potential source of radon in natural gas but with different characteristics in terms of processing, transit time and dilution. Therefore, it would be appropriate to determine the initial radon concentrations in natural gas from fracturing sources. The UK has established capability to measure radon levels in various media including indoor air, water and natural gas (UK radon 2012). It would be worth reviewing the existing assessment against the parameters that might apply to shale gas extraction to determine the potential significance of this pathway.

Radon contamination of water is judged unlikely to be a significant public exposure pathway, primarily because of the great depth at which fracturing takes place and the relatively long transit times involved. However, it is recommended that measurements of radon should be included with other measurements of contaminants in ground water and flowback water.

6 NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM)

6.1 Introduction

Naturally Occurring Radioactive Materials (NORM) are materials which contain primordial radionuclides as they occur in nature, such as isotopes of radium, uranium, thorium, potassium, and the products of their radioactive decay. The presence of NORM is already well known in the oil and gas exploration and production industry, and in particular the processes by which NORM can be transported from the oil/gas reservoir to above-ground installations and onwards. The levels of NORM encountered are highly dependent on the local geology: in some cases they are no higher than those in the general environment, and in other cases significant quantities of NORM are present, such that protective actions are necessary. NORM are present in the residues (cutting fluids and mud) produced by the initial drilling, although the levels are usually similar to those in the ground beneath, and are not of specific concern. Isotopes of radium (^{226}Ra and ^{228}Ra), due to their greater solubility, and their decay products can be present in flowback water, and more specifically in the formation water, and may also be concentrated in process residues such as scales and sludges.

The potential for radon (^{222}Rn) exposures due to releases from shale rock formations is discussed in Section 5.

6.2 Activity concentration in shale gas rock formation

Information has been published about measurements of activity concentrations of NORM in flowback water from shale gas extraction. In the USA the Marcellus Shale formation is known to contain concentrations of NORM such as ^{238}U and ^{226}Ra at higher levels than surrounding rock formations. Some radiological data have been requested from surveys carried out for the Marcellus shale in different areas of the Appalachian Basin (New York, Pennsylvania and West Virginia) (New York State Dept. of Environmental Conservation 2011). Measurements of activity concentrations of ^{226}Ra in drill cuttings and core samples from in the Marcellus were in the range 32 to 68 Bq kg^{-1} (0.87 to 1.84 pCi g^{-1}) while activity concentrations of ^{226}Ra and ^{228}Ra in flowback water were in the range 0.1 to 1.2 Bq l^{-1} (2.6 to 33 pCi l^{-1}) and 0.043 to 0.68 Bq l^{-1} (1.2 to 18 pCi l^{-1}) respectively (New York State Dept. of Environmental Conservation 2011).

The US EPA (US EPA 2012) reported generic levels of radionuclide concentrations measured in various media (scales, sludge, produced water) in oil and gas deposits. Activity levels of radium in flowback water were reported to be in the range 0.004 to 330 Bq g^{-1}; the average activity concentration of radium (^{226}Ra and ^{228}Ra) in scales was reported to be 1.8x10^{4} Bq kg^{-1} but could be as high as 1.5 10^{7} Bq kg^{-1}. In the case of sludge, the average activity concentration of radium (^{226}Ra and ^{228}Ra) was reported to be 2.8x10^{3} Bq kg^{-1}, while activity concentrations of ^{210}Pb could be as high as 1.0x10^{6} Bq kg^{-1}. The US EPA website also reports dose rates from contaminated equipment of 0.3 to 0.6 µSv h^{-1}, about 5 times the dose rate from natural background.

In the UK, the analysis of flowback water from exploratory drilling in Lancashire (Cuadrilla Resources Ltd at Preese Hall) by the Environment Agency (EA 2012) detected a number of radionuclides of natural origin, including ^{40}K, ^{212}Pb, ^{214}Pb, ^{214}Bi, ^{228}Ac and ^{226}Ra. The highest levels measured were for ^{226}Ra where activity concentrations in flowback water were between 14 and 90 Bq l^{-1}, while activity concentrations in suspended solids were in the range 2.5 to 7.2 Bq kg^{-1}. These values are consistent with activity concentrations of ^{226}Ra measured in water (range 0 – 200 Bq l^{-1}) and soil (5 – 900 Bq kg^{-1}) in Europe.

6.3 Preliminary Risk Assessment

The statutory limit for the annual effective dose to members of the public is 1 mSv. The dose for comparison with this limit is the sum of all the doses which a member of the public receives from exposure to all regulated practices at a location. It therefore includes the summed exposure from multiple fracking operations and also contributions from other installations, such as a nuclear facility, located close to the shale gas field. There are also dose constraints which apply to the exposures from individual sites.

It is difficult to fully assess radiation risks to people residing in the vicinity of facilities used for the extraction of shale gas as the assessment of the radiological consequences to these people requires a detailed knowledge of the location of the facility as well as the habits of the population and the procedures used to treat and dispose of any waste containing NORM. However, some information is available on doses to workers and members of the public from NORM from oil and gas extraction. Workers involved in the offshore oil and gas industry receive doses of between a few tens of µSv a year to a few hundred µSv a year (Strand T 2004) ; maximum doses of about 1 mSv y^{-1} were estimated for workers heavily involved in decontamination of separators. Doses to members of the public from the operation of a single well can be anticipated to be substantially lower.

Subject to the activity concentrations present in NORM, the disposal of waste produced by a facility engaged in shale gas extraction and related activities may require an environmental permit granted under the Environmental Permitting (England and Wales) Regulations[*] for the accumulation and disposal of radioactive substances. The radium activity concentrations measured in flowback water are likely to warrant such a permit.

In general, such a permit would be granted subject to the results of an assessment of the radiological consequences to workers and members of the public, aimed at demonstrating that the radiation doses to members of the public from a single installation are below the relevant dose constraint of 0.3 mSv per year. However, it is expected that the waste management process will be optimised through the application of Best Available Techniques, such that the maximum dose to a member of the public is well below this value. When evaluating permit applications it is important that the regulatory authorities should take into account the summed radiation exposures to the public from potential multiple shale gas extraction operations and, if necessary, any other sites (e.g. nuclear operations) potentially exposing the public to radiation as specified in the Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment (EA 2012).

[*] In Scotland such permits are granted under the Radioactive Substances Act 1993

6.4 Summary

In common with other forms of oil and gas exploration and production, shale gas extraction may produce process residues and waste that contain naturally occurring radioactive materials (NORM). Many of the process residues such as drilling cuttings and fluids, scales and sludges are similar to those produced in the wider oil and gas industry, and there are established waste management arrangements for dealing with these. However, shale gas extraction also produces flowback water which may be produced in significant quantities, and (depending on the geology) contain significant levels of NORM. Consequently, the site waste management arrangements need also to specifically address appropriate management of flowback water (including, as appropriate, storage, treatment, transport and disposal).

Currently, the UK has no commercial shale gas extraction operations, and so there is no UK information relating to enhanced levels of radionuclides of natural origin near shale gas extraction facilities. Activity concentrations of NORM measured in flowback water and suspended solids during exploratory drilling in Lancashire were in the range of values measured in similar environmental media in Europe. On the basis of these measurements and of the assessment of doses to workers involved in the offshore oil and gas industry it is not expected that the extraction of shale gas would pose a significant radiological risk to the public. In addition the existing regulatory structure in place in the UK is robust and is designed to protect the health of workers and the public from work activities involving NORM. Compliance with these regulations should ensure that the impact on public health from the management and disposal of NORM produced by shale gas extraction is not significant.

It would be useful for PHE to carry out a public health risk assessment prior to commercial extraction of shale gas, taking into account relevant guidance (e.g. Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment and guidance published by the National Dose Assessment Working Group (NDAWG 2012)). This risk assessment should be based on measured levels of radioactive contamination of the flowback water and other relevant media and, where necessary, should consider the potential for multiple drilling installations to be licensed within the same shale field with the consequent cumulative exposure of the same population groups.

6.5 Gaps in knowledge and recommendations for further work

There is, at present, very limited data on the occurrence of NORM during shale gas extraction activities within the UK. Extrapolation from measurements made in other countries can indicate potential issues requiring regulation and/or assessment, but direct use of these data to inform UK exposure assessments is not possible owing to differences in geology, operational activities and population behaviours. An assessment of the radiological impact of the extraction of shale gas may require more detailed information on the activity concentrations of radioisotopes of natural origin present in the waste produced by fracking in the UK. Specific measurements of activity concentrations in the materials containing NORM (flowback water, scales, sludge, brine) as well as dose rates for external exposure is required to give reliable estimates of the possible doses received by members of the public.

In general such an assessment could be based on generalised data for the UK; however more specific information on the location of the facility, its proximity to habitations, as well as habit data of people living in the area would enable PHE to estimate more accurately the radiological impact of NORM in shale formation on the local population. Information on the work practices adopted by the companies carrying out the drilling and on the processes used to treat, store and dispose of the wastes containing NORM would also be useful to perform a detailed assessment of the doses received by the workers.

7 WATER AND WASTEWATER

7.1 Introduction

This section is concerned with direct impacts on groundwater and surface water resources, and the implications for public health. It also considers the potential impacts arising from flowback water.

The process of hydraulic fracturing currently requires large amounts of water and sourcing this water may be difficult in areas where water is scarce such as in drought or low rainfall conditions. Finding sustainable sources of water is clearly important. Options may include recycling wastewater so that it can be re-used or using waterless fracturing fluids such as gels or gases. However more research is required to ascertain the efficiency and productivity of such types of fluids. The use of saline water from deep aquifers is also being considered in some parts of the USA.

Disposal of flowback waste water during shale gas extraction processes may also present potential public health risks due to the chemical constituents and large volumes of water involved. Flowback water can be treated, recycled or stored. Some operators in the USA have stored flowback water on site in man-made ponds or open pits, but stored water may evaporate which can increase the concentration of dissolved substances and so further increase the potential public health risks associated with storage on-site. However, the UK regulatory approach is not expected to to permit this practice.

Storage of fracking fluids and flowback water on-site can lead to accidents and potential releases to the environment from volatilisation of methane and other chemicals in the water. There is also the risk of stored fracking fluids and flowback water entering nearby surface water bodies or infiltrating into the soil and near-surface ground water. Such leakage may potentially affect drinking water resources if formal accident and contingency plans are not in place (UP EPA 2012) [26].

Experience in the USA suggests that the amount of flowback water may present storage issues and may exceed the processing capacity of the site. Some operators have disposed of flowback water by injecting it back into disposal wells which are typically depleted oil and gas wells located in areas that have porous and permeable rock strata. Other operators have processed flowback water for reuse in the fracking process. Although this may be a costly process, it reduces water use. In the USA, a proportion of the flowback water has been reused although the feasibility of reuse is dependent on salinity and the concentration of various chemical constituents picked up during flowback. Currently, the reuse of flowback water is limited but as technology advances it is likely that the volume of flowback water that is treated and processed for re-use will increase. Developments in recycling flowback water can have great benefits in that it can reduce the burden on water sources where supplies are limited. Flowback waters in Europe are expected generally to have high salinity due to their predominant marine origin which may reduce the potential for reuse (Broderick J et al 2011).

7.2 Evidence on key pollutants and their sources

There have been no peer reviewed published investigations carried out on the impacts of shale gas extraction and related activities on controlled waters in the UK. The potential impacts of shale gas extraction and related activities on UK drinking water sources have been considered in several UK reviews, most notably by the House of Commons Energy and Climate Change Committee (House of Commons 2011), the Tyndall Centre for Climate Change Research (Energy Advisory Board 2011) and by The Royal Society and Academy of Engineering (Royal Society 2012). These reviews noted that groundwater and surface water pollution had been reported in the USA and also recommended appropriate regulatory control to prevent such cases in the UK. The need to demonstrate good well integrity was considered a key regulatory measure. Additionally the Royal Society review suggests that background levels of methane in groundwater should be measured prior to shale gas extraction commencing to establish a baseline and also notes that: “at present, the environmental regulator does not permit shale gas extraction below freshwater aquifers” which limits the potential for the contamination of drinking waters. The British Geological Survey (BGS) has been studying methane in UK groundwaters (BGS, 2012).

In the UK, the Environment Agency (EA 2012) has analysed flowback water from exploratory drilling by Cuadrilla Resources Ltd at Preese Hall in Lancashire. The results found high levels of sodium, chloride, bromide and iron, as well as elevated values of lead, magnesium, zinc, chromium and arsenic compared with the local mains water that was used for injecting into the shale.

No peer reviewed published information on impacts on groundwater or surface waters from hydraulic fracturing activities in other European countries were found, though several exploratory activities are currently underway notably in Poland. A review has been conducted by the Internal Policies Directorate of the European Parliament (European Parliament 2011) on the impacts of shale gas and oil extraction on the environment and human health. One of the recommendations from the review was a need to reassess the European Union Water Framework Directive to consider the protection of water resources from accidents due to fracking and related activities.

A further report commissioned by the European Commission (AEA Technology 2012) examined the environmental risks, legislative controls and risk management options for fracking and related activities in Europe. In a preliminary risk assessment of all phases of hydrocarbon extraction (i.e. from site identification to well abandonment), groundwater and surface water impacts were considered to present the greatest threat to people and the environment. Key recommendations relating to the need to assess risks and take actions to minimise risks include the need to:

- Conduct baseline monitoring of ground and surface water;
- Restrict fracturing in sensitive groundwater areas;
- Set quality standards for well casings;
- Limit pollutants in waste water discharges;

- Consider amendments to the Water Framework Directive and other relevant EU legislation to take account of fracking and related activities.

There are a number of reported cases of water contamination events arising from shale gas extraction and related activities and two accounts have been published in the peer reviewed literature. Osborn and colleagues (Osborn S.G 2011) took water samples from 68 drinking water wells in 2010 and reported migration of methane into aquifers, speculating that the origin was shale gas reserves. This view was challenged by a series of published letters and replies (Jackson R.B 2011) and the authors noted that no evidence for contamination of drinking water samples with fracking fluids was found, although the testing was not comprehensive for organic chemicals or other fracking fluid additives. Warner (Waner N.R et al 2012) observed migration of brine from shale gas strata to shallow waters but noted that these occurrences did not correlate with the location of shale gas wells and were consistent with reported data before rapid shale gas development in the region. However, the authors did suggest that the presence of the brine in shallow waters might suggest the presence of connective pathways between shale gas formations and the overlying shallow aquifer.

The Massachusetts Institute of Technology (MIT 2011) reviewed 43 incidents of environmental pollution related to natural gas operations (including shale) and found that almost fifty percent were related to the contamination of groundwater as a result of drilling operations. The most common cause of such contamination appeared to be inadequate cementing or casing into wellbores, allowing natural gas to migrate into groundwater zones as it was extracted. They did not find any incidents of direct invasion of shallow water zones by fracture fluids migrating through fractures created during shale gas extraction. The second major cause of contamination (33%) was surface spills of stored fracking fluids and flowback water, which can arise from a variety of causes including hose leaks, overflowing pits and failures of pit linings.

These findings are consistent with incidents investigated by the USEPA (USA EPA 2012) who reported the main cause of incidents to be surface spills of fracking fluids or flowback waters or ‘blowouts’ giving rise to uncontrolled fluid releases during construction or operation. The USEPA also identified a number of potential sources of aquifer contamination from fracking fluid chemicals, flowback water or released methane, other gases and volatiles, dissolved minerals or naturally occurring radioactive materials (NORM).

As a result of these incidents and the subsequent widespread public concern, the USEPA (USA EPA 2012) is currently undertaking a major study of potential impacts on drinking water sources. The study will examine, *inter alia*, retrospective case studies of incidents where impacts on water resources have been reported and prospective case studies potentially involving the use of chemical tracers to track the fate and transport of injected fracturing fluids. The study will also analyse existing data on the toxicity of the chemicals used in the processes as well as study some naturally occurring substances of high concern that have no existing toxicological data. The findings are expected to be published in 2014.

Additionally, regarding the impact arising from the disposal of wastewaters, contamination of Ohio river tributaries with barium, strontium and bromide has been reported (Voltz et al, 2011), following discharge of flowback water after processing at water treatment works. The authors further considered that the bromide content could increase disinfectant by-product formation in chlorinated drinking water supplies.

7.3 Preliminary Risk Assessment

Based on the information obtained to date, there are a number of shale gas extraction activities that may impact surface and groundwater (and hence have the potential to impact upon drinking water quality):

- Production and storage of fracking fluid and flowback water on site and the possibility of spills from stored ingredients or mixtures which may percolate to subsurface aquifers or may enter surface water courses.
- Well blow out during well completion resulting in contamination of surface waters and also possible impacts on ground water.
- Use of fracking fluids and possible contamination of aquifers during injection and flow back if well integrity is not maintained.
- Release of volatiles during fracking and the possibility of methane and other gases reaching aquifers through poor well integrity and/or through fissures in the strata.
- Treatment and disposal of wastewaters during transportation off-site or improper waste treatment prior to discharge, which may result in possible contamination of surface waters.
- Water resource and acquisition since large volumes are required for borehole drilling and hydraulic fracturing (not being considered in this evaluation).

Experience in the USA suggests that surface spills of chemical additives are the most likely to cause impacts upon water sources (Energy Institute, University of Texas 2012). Research studies so far have not identified the presence of fracking fluids in groundwater; but methane, possibly originating from shale beds has been detected in aquifers, indicating potential problems with well integrity.

Concerns have been raised based on incidents reported in the USA of the potential for drinking water supplies to become contaminated with chemicals and other substances arising from shale gas extraction and related activities. In the UK, drinking water originating from surface sources (e.g. reservoirs, lakes, rivers etc.) or from groundwater (aquifers accessed by boreholes) is treated to some extent. Around 99% of water supplied in England arrives at consumers' taps under the management of water companies. These public water supplies are checked against a number of water quality parameters with compliance based on measurements of water leaving water treatment works as well of random samples taken in consumers' homes. This is a situation which is different from that in the USA where water quality issues associated with shale gas extraction have typically been reported in remote areas where water is supplied by privately-accessed boreholes where there may be minimal and variable treatment of the supply and very limited testing of water quality. It is difficult to foresee such eventualities arising in the UK given that the majority of drinking water is supplied from public water supplies which have a high level of regulatory control and testing.

The potential for shale gas extraction and related activities to impact on public drinking water supplies is considered minimal as the Water Supply (Water Quality) regulations provide for the protection of the public from any substance or organism likely to cause a threat to public health. The regulations require Water Companies to assess risks to their supply systems, identify any potential hazards and have appropriate mitigation measures in place. Local Authorities will also need to consider the implications for their risk assessments of private water supplies.

Around 1% of the UK population receives their water via private water supplies which may receive minimal treatment and testing (SWI 2012). These supplies are particularly vulnerable to pollution and as a result it would be expected that the presence of private water supplies as well as overlying aquifers to be a material consideration in approving shale gas operations. The impacts of shale gas developments could also be a consideration in the risk assessment of private water supplies that would be undertaken by local authorities.

Consideration should be given to developing analytical techniques capable of detecting contaminants which might arise from shale gas extraction and related activities and for applying these analytical methods as part of environmental water quality assessments.

A number of mitigation and control measures may be identified from experiences in the USA and elsewhere. These mitigation measures can be summarised as follows:

- Site management, bunding, inventory controls of chemicals and fuels on site.
- Maintenance of well integrity.
- Full disclosure of chemicals used in fracking fluid.
- Monitoring of sensitive aquifers for specified chemicals.
- Development of appropriate analytical detection methods for chemicals used in fracking and related activities including waste products.
- Development of environmental quality standards where these do not exist.
- Containment of any expelled materials from “blow-outs” and appropriate clean up procedures.
- Warnings to users of any affected surface waters and restriction of access.
- Interception of spills before abstraction into public water supply and/or provision of advice to consumers.
- Regulatory controls on treatment works receiving waste waters from shale gas extraction activities.

Where appropriate and relevant, these control measures should be included in the permitting and operational consents granted by the principal regulatory bodies.

There have been reports of fracking fluid contaminating groundwater but this appears to be less to do with the hydraulic fracturing process and more likely the result of either catastrophic or progressive well failure resulting in leakage of fracking fluid or flowback water. Examples include poor cementation which allows fluids to move vertically through the well casing or between casings and rock formation or radial leakage where poor well casing construction allows fluid to move horizontally out of the well and migrate into the surrounding rock strata.

Contamination arising from the actual fractures does not appear to be a significant issue since the length of the fracture is relatively short compared to the depth of the well and overlying rock. Vertical well sections may be drilled hundreds to thousands of feet below the land surface and lateral sections may extend 1000 to 6000 feet (300 to 2000 metres) away from the well. The majority of fractures may be only a few micrometres in width and are usually limited in length to a few tens of metres (USA EPA 2012) . The likelihood of fracking fluid reaching underground sources of drinking water through fractures is reported to be remote where there is a separating impermeable layer of at least 600 metres between the drinking water sources and the production zone (AEA Technology 2012). Contamination from the fractures is not expected to be a viable risk to groundwater and there is no unequivocal evidence of chemicals entering local aquifers and groundwater from the actual fracturing process. The presence of aquifers should be a key consideration in the siting of any wells in the UK.

Planning and other regulatory and site operational controls, including high quality well integrity and good environmental management of surface and below ground activities should protect water sources from any adverse impacts resulting from shale gas extraction and related activities. However accidents and unintended consequences will require effective incident management procedures and appropriate planning will be required to deal effectively with such eventualities.

The EA is responsible for maintaining or improving the quality of fresh, marine, surface and underground water in England. In relation to shale gas extraction and related activities this will be through the issue of environmental permits and consents, offering pollution prevention advice, conducting compliance activities and monitoring surface and ground water quality.

7.4 Gaps in knowledge and recommendations for further work

Appropriate monitoring of aquifers and surface waters is needed to assess exposure and should be a critical part of any risk assessment process. Baseline monitoring data are required pre-drilling to establish background levels of pollution and any monitoring programme will need to continue throughout the lifetime of the well including the decommissioning of the well pad, Analytical methods capable of detecting contaminants associated with shale gas extraction and related activities may need to be developed. There is a need to consider private or concessionary abstractions close to fracturing activities and to examine the best ways of protecting the sources of these supplies. Water safety plans may offer some potential in this regard.

Clearly shale gas extraction and related activities have the potential to mobilise natural contaminants and minerals and these will vary accordingly to the geology of the area. There is a need to characterise these contaminants on a case by case basis. Agencies in the UK will need to agree criteria for correct disposal of waste water after treatment via regulation and permitting regimes.

8 HYDRAULIC FRACTURING FLUID

8.1 Introduction

Shale gas operations use a range of oil and water based fluids and treatments to allow efficient injection into the well, induce and maintain permeability and generate productive fractures. These fracturing or fracking fluids contain a range of chemicals which have a number of roles including:

- To create a fluid viscous enough to create a fracture of adequate width.
- To be able to maximise fluid travel distance to extend fracture length.

- To be able to transport large amounts of proppant into the fracture.
- Gelling properties to allow for easier degradation and reduced cost.

The composition of these fluids is dependent on many factors such as the underlying geology, the type of rock to be hydraulically fractured and operational considerations. They also vary from operator to operator. Specialised vehicles and containers are required to transport and store fracking fluids or the component chemicals. Table 1 lists the main components of fracking fluid reported in the USA and their role. It should be emphasised that not all the components listed in Table 1 would be used in the UK and the exact composition of fracking fluids proposed for use in the UK is unclear. However, operators in the UK intend to publicly disclose the chemical additives of fracturing fluids (UKOOG, 2013).

Table 1 Main reported components of fracking fluids used in the USA (Committee on Energy and Commerce 2011, US EPA 2004) [56-57]

Additive Type	Main Compound(s)	Purpose	Common use of Main Compound
Acids	Formic and hydrochloric acids	Used to dissolve the rock and create a conduit	Used in cleaning products
Acid Corrosion Inhibitors	Acetone	Required in acid fluid mixtures because acids will corrode steel tubing, well casings, tools, and tanks	Used in pharmaceuticals, fibres and nail polish remover
Biocides, bactericides or microbiocides	Gluteraldehyde	Used to kill any existing microorganisms such as bacteria and algae, and to inhibit bacterial growth and deleterious enzyme production	Disinfectant, sterilisation of medical and dental equipment
Breakers or Breaking Agents	Ammonium persulfate, ammonium sulphate, copper compounds, ethylene glycol, and glycol ethers. Also includes metal ion-cross-linked guar such as chromium, aluminium, titanium	Used to break the cross-linker and eventually the polymer. Also used to degrade fracking fluid viscosity	Bleaching agent in detergents and the production of plastics
Diesel Fuel	Petroleum product	Delivery system sometimes used to dissolve guar gum or guar based derivatives	Fuel for vehicles
Foamed Gels	Employ nitrogen or carbon dioxide as their base gas. Also contain diethanolamine and alcohols such as isopropanol, ethanol, and 2-butoxyethanol	Foam bubbles to transport and place proppant into fractures	Shaving foams, shampoos and creams
Fluid-Loss Additives	Mixture of natural gums, resins and bridging agents	Restrict leak-off of the fracturing fluid into the exposed rock at the fracture face	
Friction Reducers	Typically latex polymers or copolymers of acrylamides	Used to minimise friction	Water treatment, soil conditioner
Gels	Guar gum, guar derivatives such as hydroxypropylguar or cellulose derivatives such as carboxymethylcellulose	Creates higher viscosity fracturing fluids to transport the proppant	Cosmetics, toothpastes, baked goods, ice cream
Iron Control	Citric acid	Prevents the precipitation of metal oxides	Food additive, flavouring in food and beverage, lemon juice
Oxygen Scavenger	Ammonium bisulphate	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverages processing

Additive Type	Main Compound(s)	Purpose	Common use of Main Compound
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components	Washing soda, detergents, soap, water softener
Proppant	Silica, Quartz sand	Used to prop open a hydraulic fracture	Drinking water filtration, play sand, bricks
KCl Salt	Potassium chloride	Used to increase viscosity and increase proppant transport capacity	Low sodium table salt
Surfactant	Isopropyl alcohol	Used to increase stability of fracture fluid	Glass cleaner, antiperspirant, hair colour

8.2 Evidence on key pollutants and sources

Currently, there is no published peer reviewed literature in the UK on the likely composition and use of fracking fluids. The Royal Society and The Royal Academy of Engineering (Royal Society, 2012) have recommended a number of measures to protect groundwater from fracking fluid while the House of Commons Committee on Shale Gas (House of Commons 2011)recommended that the EA monitor flowback water to assess for potentially harmful materials. They also recommended that monitoring of groundwater should be undertaken before, during and after hydraulic fracturing operations to allow for a full assessment of any potential contaminants.

There are limited data on fracking fluid composition from UK operations. The composition of fracking fluids used by Cuadrilla during hydraulic fracturing activities in Lancashire has been disclosed. Water and sand accounted for 99.75% of the fracking fluid volume with polyacrylamide friction reducers (0.075%), hydrochloric acid (0.125%), an unnamed biocide (0.005%) and sodium salt (0.00005%) which acts as a tracer (Cuadrilla 2011).

In the UK, as in other EU Member States, the Water Framework Directive and the Groundwater Daughter Directive protect groundwater against pollution by preventing or limiting the entry of pollutants to groundwater. The Agencies responsible for groundwater protection in the UK are the Environment Agency in England, Natural Resources Wales, the Scottish Environment Protection Agency and the Northern Ireland Environment Agency. These Agencies are also responsible for identifying a list of hazardous substances and decisions as to whether substances are hazardous are reviewed by the Joint Agencies Groundwater Directive Advisory Group (JAGDAG). This is a body comprising the Agencies noted above together with the Department of Environment, Food and Rural Affairs (Defra), Welsh Government (WG), the Environmental Protection Agency Ireland (EPA), and Public Health England (specifically the PHE Centre for Radiation, Chemical and Environmental Hazards) as well as industry representatives. It is anticipated that the JAGDAG would provide an appropriate mechanism to peer-review the classification of chemicals used in fracking fluid and this would ensure that any chemicals are properly risk assessed prior to use in the UK.

Owing to commercial confidentiality there was, until recently, little disclosure of the chemical composition of fracking fluids in the USA. However, in 2010, the Fracturing Responsibility and Awareness of Chemicals Act (FRAC ACT) (FRAC ACT 2010) was introduced in the House of

Representatives and the Senate, which requires companies to disclose such details although not the proprietary formula. In 2011, the US Committee on Energy and Commerce launched an investigation into hydraulic fracturing in the United States (Committee on Energy and Commerce 2011). The committee requested 14 leading oil and gas service companies to disclose the types and volumes of the products they used in their fracking fluids between 2005 and 2009 and the chemical contents of those products. This report contained a list of over 2,500 hydraulic fracking products containing 750 chemicals and other components. This exhaustive list contained chemicals that are relatively harmless such as salt and citric acid but also substances of more concern such as benzene, toluene, ethybenzene and xylene. Table 2 summarises the main components reported to the Committee, however it should be noted that these chemicals may not be used in the UK.

Table 2 Main chemical components used in fracking fluid the USA between 2005 and 2009 (FRAC Focus 2012)

Chemical Component	No. Of Products Containing Chemical
Methanol (Methyl alcohol)	342
Isopropanol (Isopropyl alcohol, Propan-2-ol)	274
Crystalline silica - quartz (SiO_2)	207
Ethylene glycol monobutyl ether (2-butoxyethanol)	126
Ethylene glycol (1,2-ethanediol)	119
Hydro-treated light petroleum distillates	89
Sodium hydroxide (Caustic soda)	80

In addition to the House of Representatives report there have been other reviews into the composition of fracking fluids and the potential risks associated with the chemicals used. Most notably, an examination of 944 products containing 632 chemicals that were used in fracking fluids during natural gas operations (Colborn T et al 2011). Colborn et al reviewed the toxicity of 353 chemicals through literature searches and material safety data sheets and found that 75% of the chemicals reported could affect dermal, ocular, respiratory and gastrointestinal systems while approximately 40-50% of the chemicals could affect the nervous or immune systems. In addition, 37% of the chemicals reported could affect the endocrine system; and 25% were potential carcinogens or mutagens. Information on the remaining chemicals was not obtained due to lack of full disclosure and appropriate Chemical Abstract Service (CAS) number identification. The authors concluded that, despite the relatively small amounts of these chemicals in the overall fracking fluid, the potential health impact of such chemicals warrants full disclosure of all chemical products, strict regulation and comprehensive air and water monitoring.

FracFocus (FRAC Focus, 2012) is the national hydraulic fracturing chemical registry for the USA and is managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission. The chemical data presented on this site has been submitted on a voluntary basis by the participating oil and gas companies. The site was created to provide information about chemicals used in fracking fluid, and also provides details of the chemical substance, its purpose and its function within the fluid.

The Province of New Brunswick, Canada has also announced that companies will be required to make a full disclosure of all chemicals used in fracking fluid. A report by the Chief Medical

Officer of Health (Office of the Chief Medical Officer of Health, New Brunswick 2012) went further and recommended that the requirement for disclosure should cover all chemicals used by the shale gas industry, be publicly available and disclosed in a timely fashion and with sufficient lead time to be included in human health and environmental risk assessments.

8.3 Summary

It is likely that there will be many differences in the use and composition of fracking fluid in the UK compared with the USA. Data in the UK are currently limited to one site and one operator and experience in the USA suggests a wide variety in the use and composition of fracking fluids between operators and in different regions. Potentially a wide range of chemicals can be used including many of which are classified as highly toxic and/or carcinogenic. Geological and operational considerations are the main factors determining the choice of chemicals used. Experience in the USA shows that full disclosure of the chemicals is essential for a robust risk assessment and recent developments have put the emphasis on transparency of reporting.

Although the concentration of individual chemicals in the fracking fluid is low, the amount of fracking fluid that is required means that the volumes of these chemicals could be significant. The quantity and concentration, route of exposure and eventual fate will determine the level of risk associated with the chemicals used in the fracking fluid. It is, therefore, strongly recommended that any chemicals used are fully disclosed and subject to independent assessment prior to use in fracking and related activities. The JAGDAG is recommended as the appropriate group to assess risks to groundwater.

Well design and construction is an integral part of controlling the risk from fracking fluid. Fracking fluid is injected at high pressures to keep fractures open and well integrity is vital in order to prevent fluid from leaking out of the well. However, there have been cases in the USA where surface or subsurface blowouts have occurred (Massachusetts Institute of Technology, 2011)and such events have caused contamination of surrounding land and groundwater.

Accidents from surface activities such as handling and processing of fracking fluids can also cause contamination of groundwater and surrounding land. Such incidents can be reduced by implementing high standards and best practices when handling and processing fracking fluids. Accident management plans and strict enforcement by regulatory bodies will further reduce the risk of accidents. Evidence from the USA suggests that many of the chemicals used to produce fracking fluids are mixed on site. This requires chemicals to be stored and handled in a more concentrated form and good on-site management and plans are needed to minimise the risk to workers, the public and the environment.

8.4 Gaps in knowledge and recommendations for further work

There are significant gaps in the literature about the identities and quantities of the chemicals within fracking fluids and available data are mostly based on activities in the USA. It is likely that the composition of fracking fluids used in UK will be different to those used in the USA. Full disclosure of the chemicals within the fracking fluid is a critical part of any risk assessment process and will allow better understanding of the technologies required to adequately treat and process fracking fluids for re-use. A comprehensive regulatory framework at the permitting and planning stage is required in the use, handling and disposal of fracking fluids and this should include an assessment of chemicals in fracking fluid undertaken by the JAGDAG.

As noted in Section 7 there is a need for baseline monitoring of aquifers and surface water prior to fracking and related activities as well as continuing monitoring during and after production. Any monitoring programme needs to focus on the detection of the chemicals used in the fracking fluid.

Chemical handling and storage of fracking fluids should adhere to clear and robust guidelines. As to minimise the potential for accidents and potential releases into the environment. Formal accident and contingency plans should be in place to allow for appropriate and timely response to any eventuality.

9 ROLE OF HEALTH IMPACT ASSESSMENT

If commercial scale shale gas developments are considered, it is important to determine how best to evaluate health issues prior to operation. There are a number of potential tools and methods that could look at the health impact of shale gas extraction and related activities e.g. human health risk assessment, environmental impact assessments or strategic environmental assessments. Health impact assessment (HIA) is particularly promising in light of its broad applicability, its focus on adverse and beneficial health effects, its ability to incorporate various types of evidence, and its emphasis on stakeholder participation. In New Brunswick, Canada, the Chief Medical Officer of Health (House of Commons, 2011) made a number of recommendations concerning shale gas development including a strong commitment to use HIA as a tool in the regulatory process to protect health from changes in both the social and physical environments.

There is one notable HIA in the literature. The Colorado School of Public Health in 2011 undertook a comprehensive HIA in a shale gas development area (Colorado School of Public Health 2011) . This study identified potential risks related to chemical exposures, accidents, psychological impacts (such as depression, anxiety and stress) and social impacts, and proposed over 70 recommendations for minimizing the risks. This HIA looked at the impact on a local community of a large shale gas development potentially incorporating up to 200 individual gas wells. It looked at a range of issues from the impact of emissions to air, land and water, noise and visual impact, transportation to and from the site, the health profile of the local community, economic benefits and broader social issues such as the impact of workers on the infrastructure of the local community. At present there is no development on such a scale planned for the UK but should commercial scale operations be planned, HIA may be considered as a useful tool to assess the impact on public health of shale gas extraction and related activities.

HIA have been used to assess a range of policies, plans and individual projects (such as planned industrial facilities) in the UK. HIAs may be undertaken by consultants for industry to determine the potential impact of their proposals and these may also be subject to review by other agencies such as local public health professionals. Often the methods used in a HIA form part of other impact assessment strategies such as Strategic Environmental Assessments (SEA) or Environmental Impact Assessments (EIA).

While the Colorado HIA is the only comprehensive published HIA, other health impact studies have considered specific issues associated with shale gas extraction and related activities such as the chemicals used in fracking fluid and drinking water impacts. Regarding the latter, the USEPA is currently conducting a study to understand better any potential impacts of fracking on drinking and ground water.

The boundaries for a HIA or any other form of impact assessment such as an SEA for shale gas development and production would need careful definition and design. The objectives of a HIA would differ on a case by case basis depending on the definition of health used, the type of development, the scale of the operation, the availability of data and the specific health outcome or issue under consideration. Lack of data and information may make a HIA difficult. As is clear in this report, accurate data on likely exposures and impacts are limited or not yet available.

HIA can often be time and resource intensive; depending on their scope they can take months or even years. The scale and size of the development under consideration is also another key factor since a HIA around a single drill site may have limited value. Therefore, the potential of HIA to assess shale gas activities remains to be determined and HIA may not be needed for all developments. The National Academy of Sciences in the USA has recently discussed the potential value of HIA for new shale gas developments, while in the UK HIA has been typically used to assess the impact of large scale developments or strategic policies and plans (e.g. waste management facilities). Clearly, health impacts of shale gas developments will need to be thoroughly assessed and HIA offers a useful tool to fully assess the health consequences of such developments. As a result consideration should be given to integrating the principles and methods of HIA early on in the planning process.

10 SUMMARY

This initial review has focused on the impact of direct releases of chemicals and radioactive material from shale gas extraction and related activities. Other considerations, such as groundwater abstraction and water sustainability, noise, traffic (apart from vehicle exhaust emissions), and visual impact have not been addressed. However, should commercial scale shale gas extraction be introduced, such issues will need careful evaluation on both a national and local scale.

Although shale gas extraction and related activities have the potential to cause pollution to air, land and water, the currently available evidence indicates that the potential risks to public health from exposure to the emissions associated with shale gas extraction are low if the operations are properly run and regulated. Most evidence suggests that contamination of groundwater as a result of borehole leakage is an area of concern, but that contamination of groundwater from the underground fracking process itself is unlikely. However, other impacts such as spills and accidents above ground, emissions to air etc. are also potentially significant.

There is, to date, little peer reviewed research but experiences from countries with commercial scale operations, particularly the USA, demonstrate that good on-site management and appropriate regulation of all aspects of the operations, from exploratory drilling to gas capture and use and storage of fracking fluid, is essential to minimise the risk to the environment and public health. It is also clear that the well-publicised problems in the USA appear to have been due to operational failures and inadequacies in the regulatory environment. Such problems may not be replicated in the UK since our geology, topography, mode of operation and, most importantly, the regulatory environment will be significantly different. This makes it difficult to extrapolate from the experience in the USA.

The risks from small scale drilling for exploratory purposes (e.g. single wells) are also clearly different from the risks from commercial scale operations. The potential health impact from single wells is likely to be very small, although the cumulative impacts of many wells in various phases of development in relatively small areas will need careful scrutiny.

This review suggests that good regulation of all aspects of shale gas exploration and extraction should minimise the potential impact on the environment and public health from direct releases of chemicals and radioactive material. In addition further work is needed on baseline monitoring, development of emission inventories and monitoring programmes during and post production, early toxicological assessment of chemicals used in fracking fluids and the cumulative impacts of multiple wells. Future research questions should address concerns about analytical capacity to monitor for pollutants associated with shale gas extraction and related activities and the development and use of tools such as HIA to assess public health implications.

Public Health England anticipates a low risk to public health from direct releases of chemicals and radioactive material if shale gas extraction is properly operated and regulated. Shale gas developers and operators, through the planning and environmental permitting processes, will be required to satisfy the relevant regulators that their proposals and operations will minimise pollution and risks to public health. PHE will provide support by responding to requests to assess impacts on health in specific cases.

11 RECOMMENDATIONS

This is an initial review and further work is suggested to define better the potential health impact of shale gas extraction. The drilling of exploratory wells offers an opportunity to collect a comprehensive set of data on shale gas extraction and related activities. These data should contribute to an improved evidence-base to inform UK risk assessments. HIA or similar approaches are a means of assessing the wider impacts of shale gas extraction and related activities on both a local and regional scale.

Each section has identified a number of gaps in knowledge and potential areas for further work. A number of key recommendations for further work are proposed:

- Public Health England needs to continue to work with regulators to ensure all aspects of shale gas extraction and related activities are properly risk assessed as part of the planning and permitting process.
- Baseline environmental monitoring is needed to facilitate the assessment of the impact of shale gas extraction on the environment and public health. There should also be consideration of the development of emission inventories as part of the regulatory regime.

- Effective environmental monitoring in the vicinity of shale gas extraction sites is needed throughout the lifetime of development, production and post-production.
- It is important to ensure that broader public health and socioeconomic impacts such as increased traffic, impacts on local infrastructure and worker migration are considered.
- Chemicals used in fracking fluid should be publically disclosed and risk assessed prior to use. It is useful to note that any potential risk to public health and the environment from fracking chemicals will be dependent on the route of exposure, total amount and concentration, and eventual fate of any such chemicals. It is expected that these aspects will be considered as part of the regulatory environmental permitting process.
- The type and composition of the gas extracted is likely to vary depending on the underlying geology and this necessitates each site to be assessed on a case by case basis.
- Evidence from the USA suggests that the maintenance of well integrity, including post operations, and appropriate storage and management of fracking fluids and wastes are important factors in controlling risks and appropriate regulatory control is needed.
- Characterisation of potentially mobilised natural contaminants is needed including NORM and dissolved minerals.

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13 ADDENDUM

PHE has continued to assess the scientific evidence on the potential public health impacts of exposures to chemical and radiological pollutants associated with shale gas extraction, the references below have been reviewed and are not considered to affect the conclusions of the draft report. PHE invites submission of additional relevant articles from the scientific literature for consideration if these have not been considered in the report or identified below.

A link to official guidance from UK Government organisations and associated bodies has also been provided for ease of reference.

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https://www.gov.uk/oil-and-gas-onshore-exploration-and-production