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NORM issues associated with shale gas exploration and production

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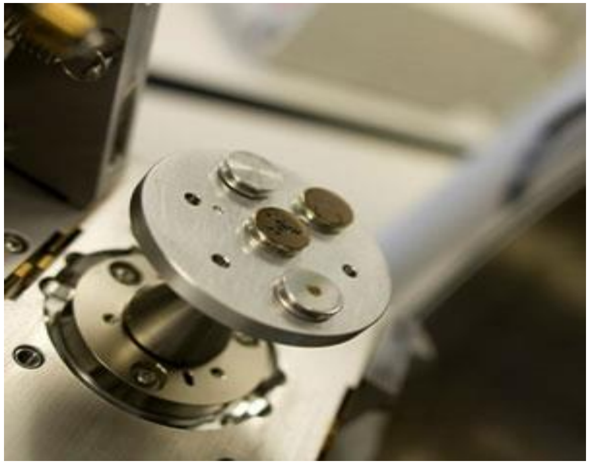
The National Nuclear Laboratory

- National Nuclear Laboratory established in 2008
  - Formed out of the old R&D Department of BNFL
  - 3+1+1 year M&O contract awarded to SBM (Serco Batelle Manchester University)
- Three Business Units

Waste Management & Decommissioning

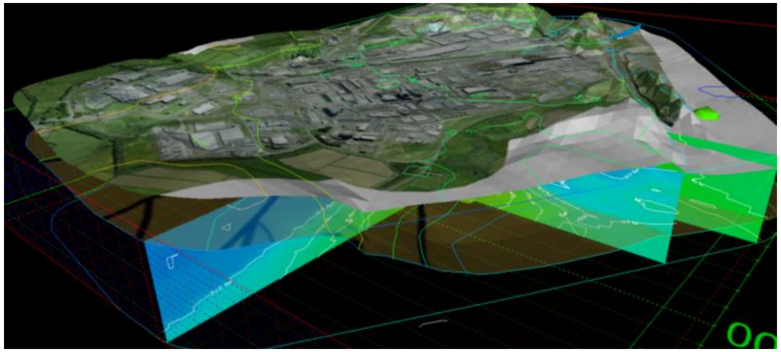
Fuel Cycle Solutions

Reactor Operations Support



NNL environmental capability

- Provides a broad and comprehensive range of technical services covering all aspects of radioactive waste disposal, contaminated land and environmental aspects of nuclear site operations.
- Extensive experience of working and delivering in a tightly regulated environment
- Capabilities and expertise includes:
  - Contaminated Land Assessment
  - Site Characterisation
  - Environmental risk assessment
  - Environmental safety cases
  - Radioactive waste management and disposal
  - Effluent treatment
  - Remediation
  - Regulatory Permissioning
- Encompasses
  - Field work
  - Experimental capability – lab to rig scale
  - Modelling – groundwater flow, contaminant transport, dispersion modelling, geochemical modelling, dose and risk assessment



Overview

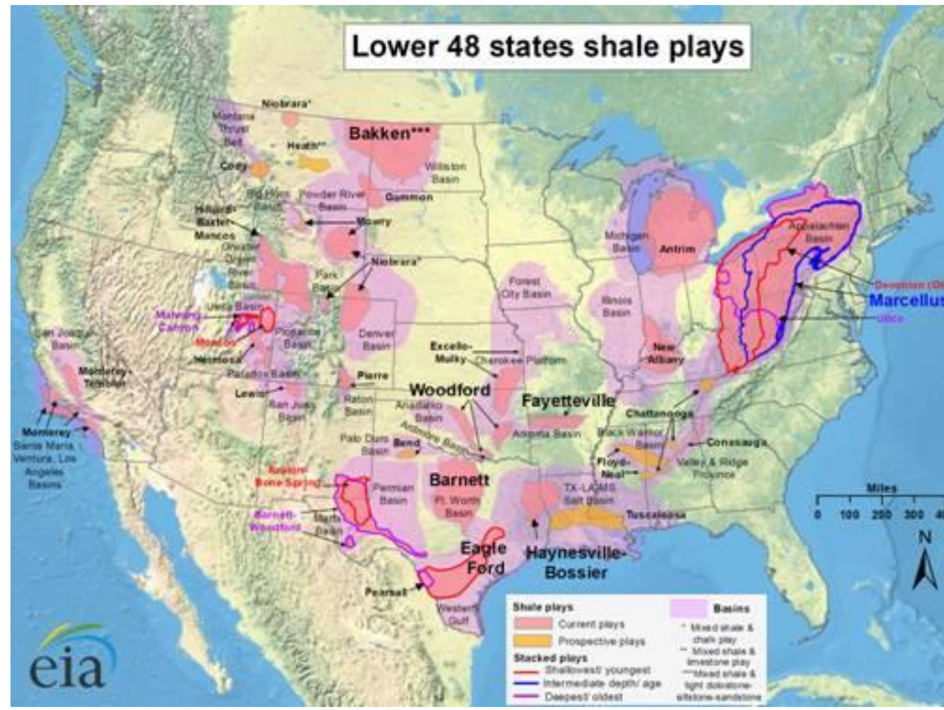
- About shale gas exploration and production
- Flowback and produced water
- NORM issues
- Disposal routes
- Environmental risks associated with transport of NORM contaminated waste flow-back fluid

Unconventional gas reservoirs

- Conventional reservoirs – comprise a structural/stratigraphic trap in permeable rocks to which gas has migrated
- Unconventional reservoirs – gas held in low permeability rocks requiring horizontal drilling and hydraulic fracturing ('fracking') to recover gas economically
  - Established techniques widely used in conventional oil and gas extraction
  - Rising gas prices and advances in technology have made exploitation of unconventional reservoirs economic

History

- Shale gas first extracted from Marcellus Shale (Pennsylvania/NY state) in 1821
  - small-scale, local use – no fracture stimulation
- Large-scale shale gas production in North America from ~2005
  - 40,000 shale gas wells drilled
  - Currently 23% of total US gas production



•Worldwide, shale gas estimated to increase recoverable gas resources by 40%

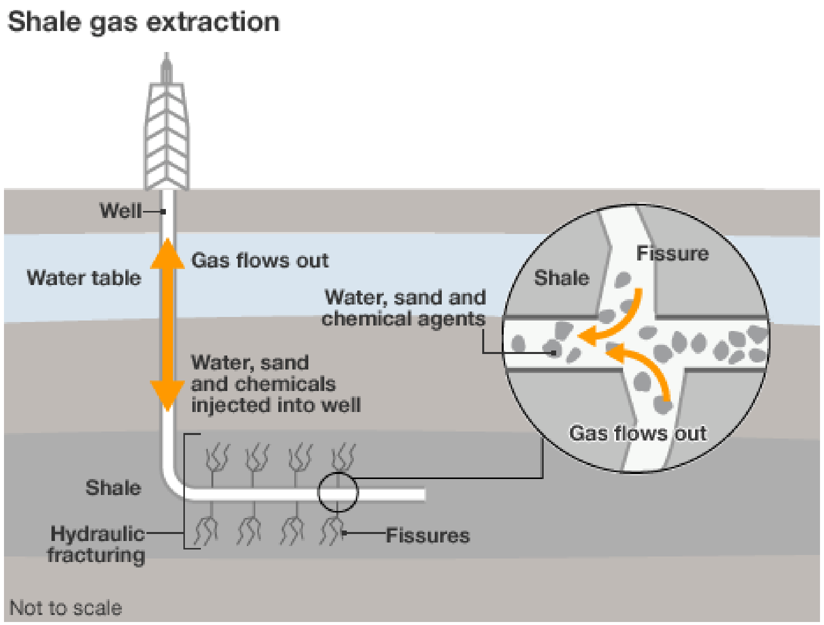
European shale gas plays

Country	Shale gas reserves	
	Billion m³	Years
Poland	5,295	322
France	5,097	104
Norway	2,350	519
Ukraine	1,189	27
Sweden	1,161	1,025
Denmark	651	144
UK	566	6
Romania, Hungary, Bulgaria	538	20
Netherlands	481	10
Turkey	425	12
Germany	227	2
Lithuania	113	40

Based on current domestic consumption
Source: US Energy Information Administration 2011

Well development

- Horizontal drilling maximises well surface area through shale
- Well casing perforated in "payzone"
- Fracking involves injection of high pressure water (with additives) to stimulate gas flow
  - Tens of thousands of litres of water
  - Proppant – sand or ceramic beads
  - Chemicals including:



- •Biocides – prevent biofouling
- •Weak hydrochloric acid – disperses residual drilling mud
- •Gelling agent – holds proppant in fluid
- •Liquefier/breaker – releases proppant once penetrated fractures
- •Friction reducer, e.g. polyacrylamide – reduces pressure needed to pump water
- •Salt (NaCl) - tracer

Flowback and produced water

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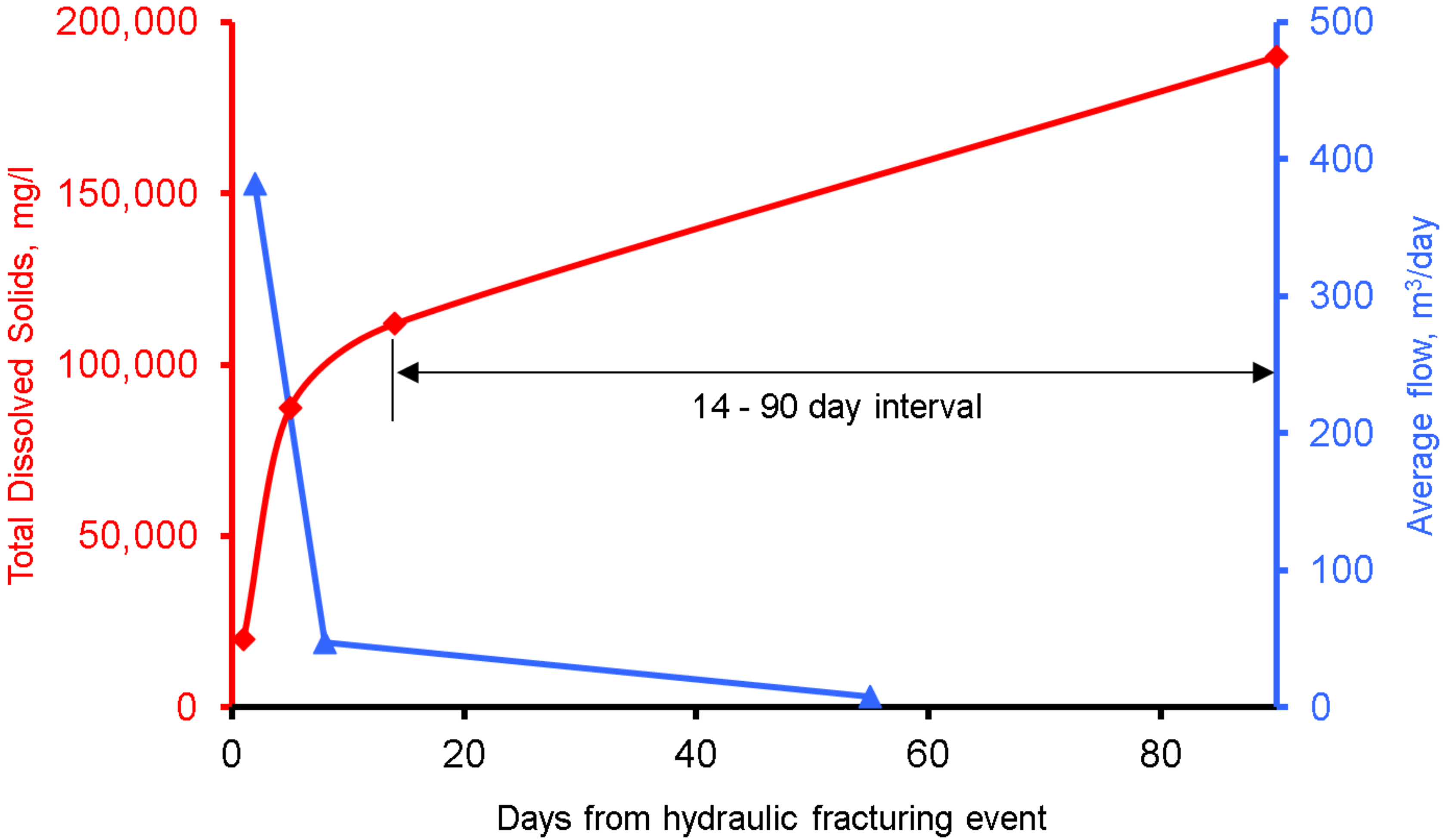
- Typically >10,000 - 20,000 m3 water required to frack each well
- 15-80% returns to surface within few weeks as "flowback water"
  - In US, frequently stored in surface lagoons pending reinjection, reuse or treatment + surface discharge
  - In UK, stored in tanks pending disposal
- Much of remaining fracking fluid returns to surface with gas during well lifetime
- Wells also generate formation water ("produced water") at lower rate throughout lifetime

Produced water

- UK oil and gas industry:
  - 214 million m^3 produced water per year
  - Onshore fields contribute 1.4% of oil and 0.3% of gas, but 4.3% of total produced water
- Proportion of produced water increases over lifetime of field
- Gas fields tend to generate less produced water than oil fields, but higher concentrations of minerals
- Compositions variable and field dependent – high salinity (TDS)
- Typical values (mg/l except pH):

	pH	TDS	As	Ba	Hg	Pb	Cd	Cu	Ni	Zn
Produced water - North Sea oil[2]			0.003	0.1	0.000	0.7	0.0	0.01	0.08	0.7
Produced water - North Sea gas[2]			0.002	2	0.004	0.1	0.1	0.03	0.05	14.0
Flowback - Marcellus Shale[3]	6.2	120,000		686						
Flowback - Preese Hall shale gas well	6.2	168,750	0.487	19	0.000	0.1	0.1	0.19	0.17	0.2

Typical profile of flowback rate and salinity over time



Preese Hall shale gas well flowback water

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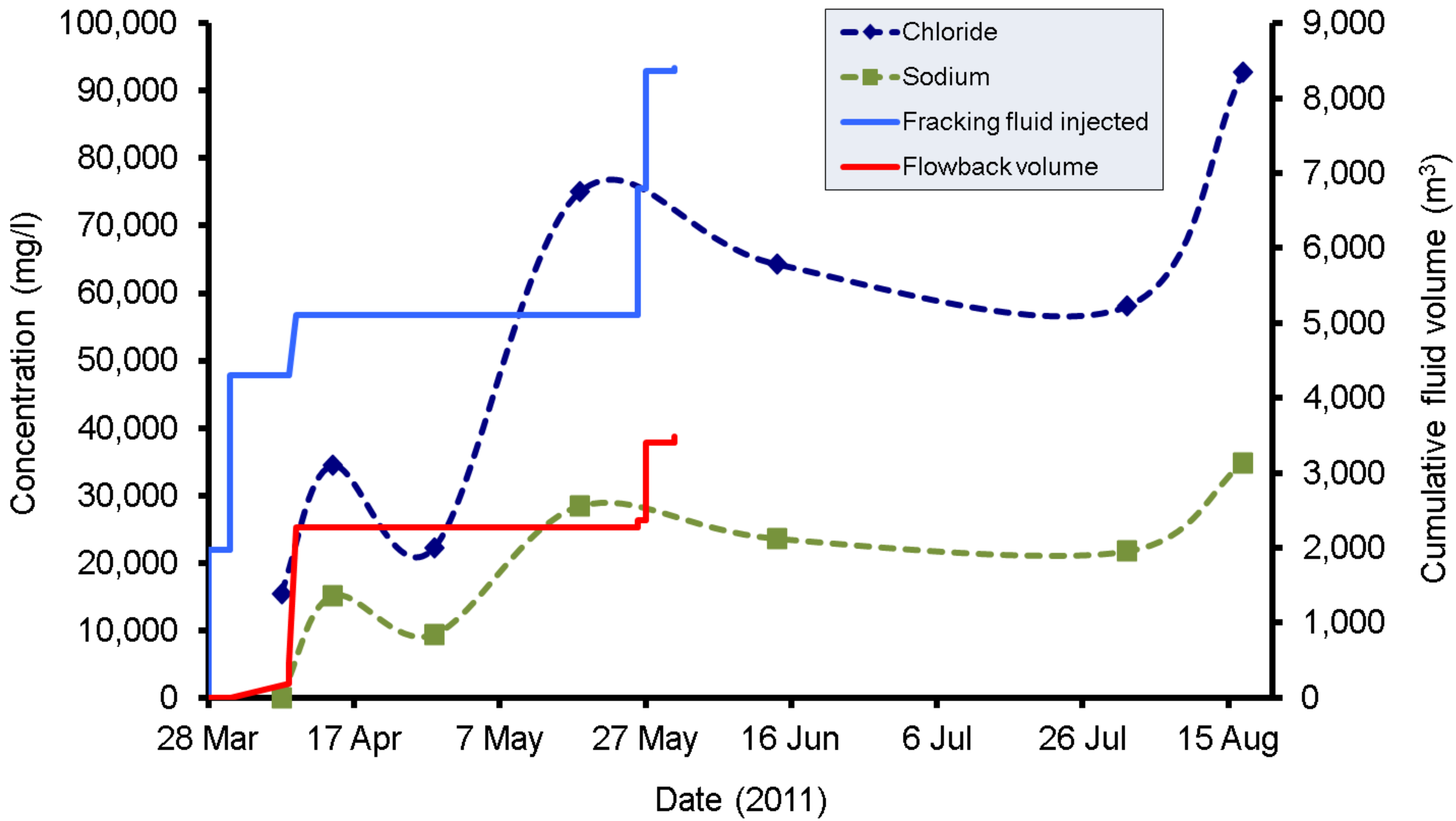
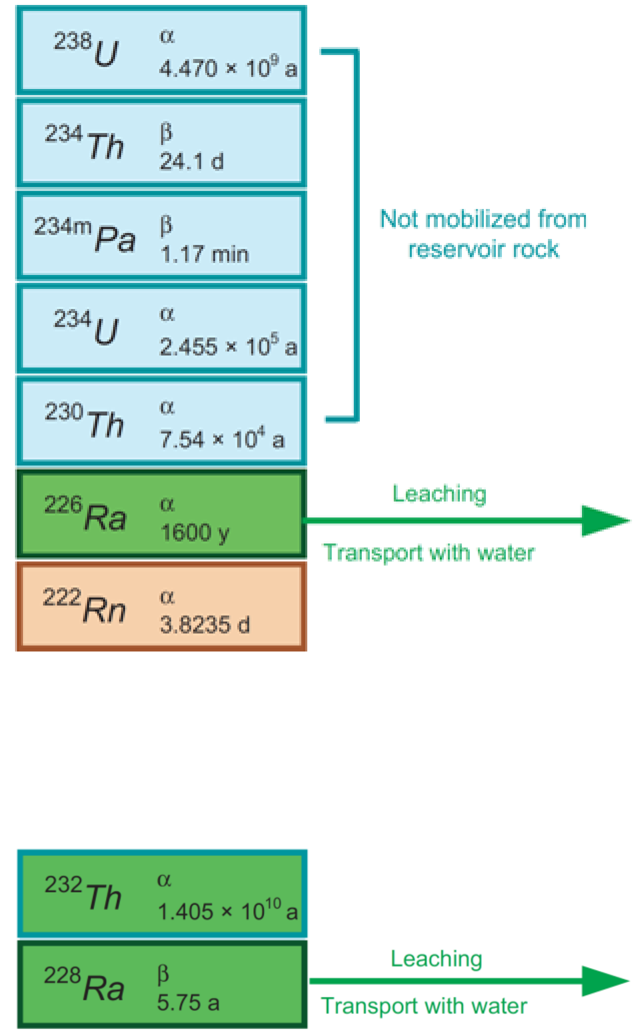


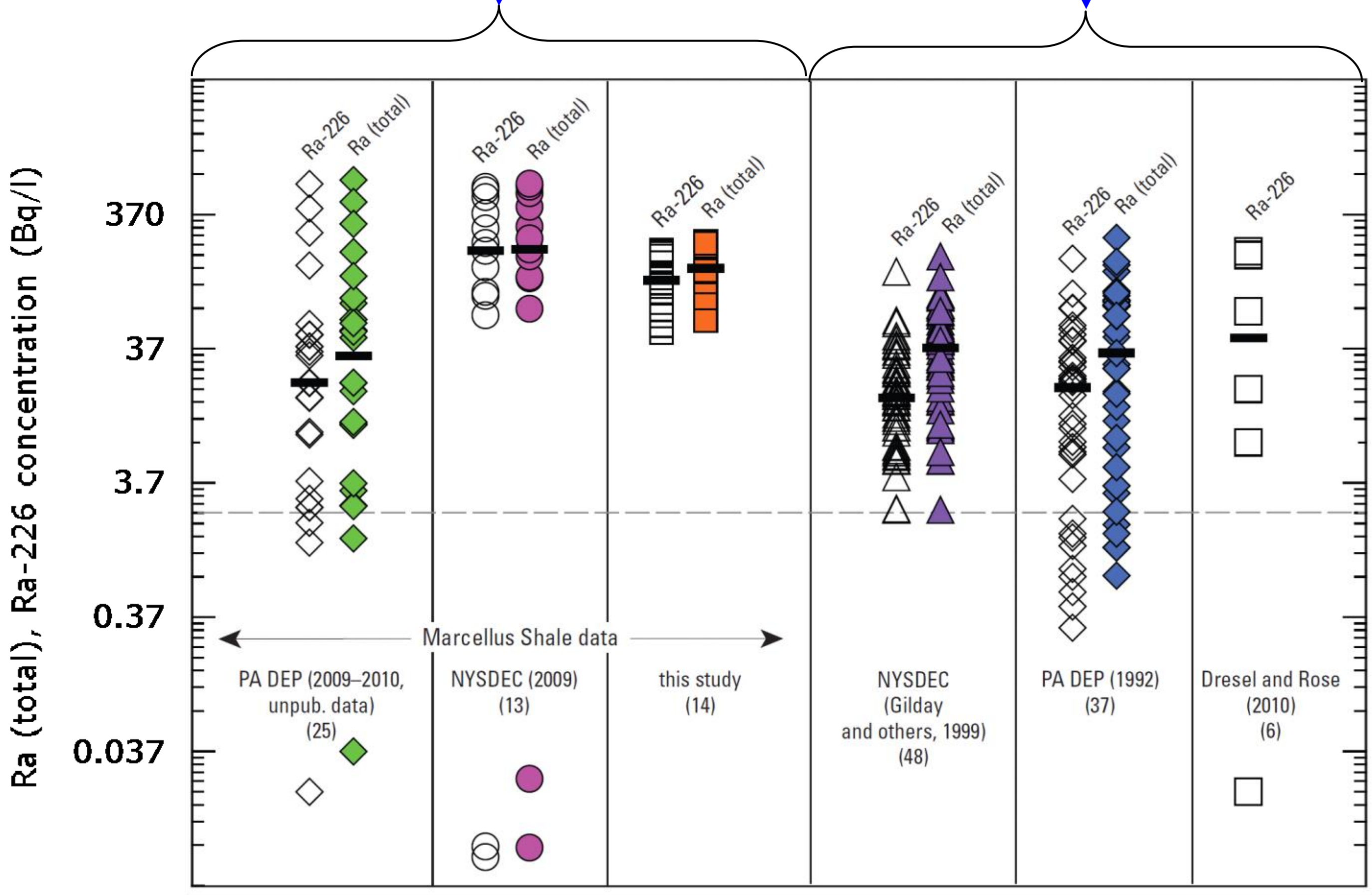
NORM issues

- Clay-rich formations such as shales naturally high in U-238 and Th-232
- Radium decay products slightly soluble
  - In equilibrium with pore water
  - Ra-226 typically ~3x Ra-228
  - Concentrations of other NORM radionuclides generally lower
- Ra concentrations proportional to salinity
  - Salt ions compete with Ra2+ for adsorption sites primarily on clay minerals, reducing Kd
- Ra concentrations typically highest close to well head
- When brought to surface, Ra either stays in solution or may co-precipitate with Ba, Sr and Ca, forming NORM 'scale'



NORM concentrations

- Water from shale gas wells typically has higher NORM concentrations …..than from conventional gas wells



NORM analyses

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- Flowback water analyses from Preese Hall exploratory well are within ranges of published data
- Exemption thresholds exceeded (highlighted) - Permit required for disposal

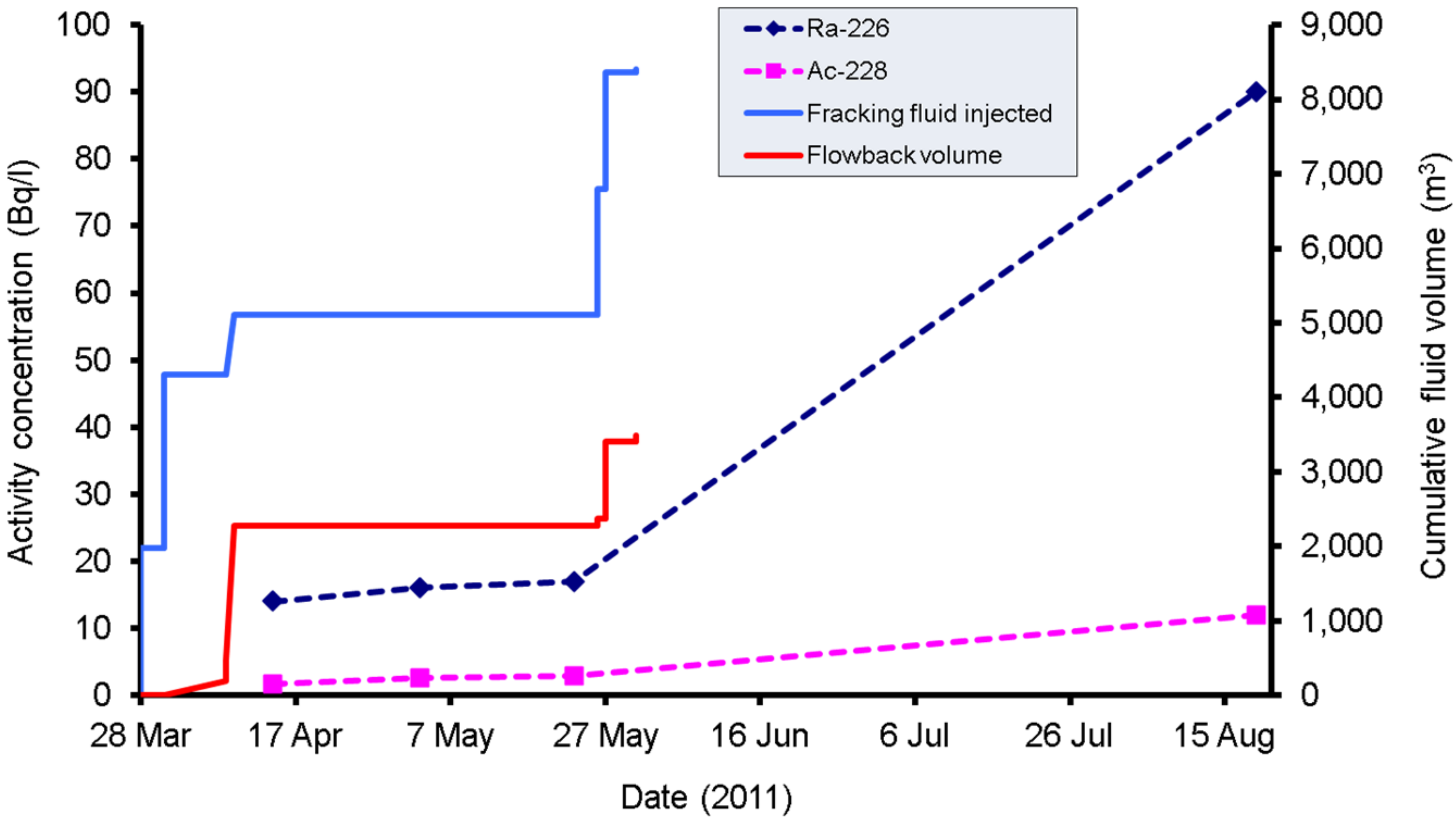
Published data (Bq/l)

		Typical	Max
Flowback - Marcellus Shale[2]	Total Ra	91	666
Flowback - non-Marcellus[2]	Total Ra	27	248
Produced water[3]	Ra-226	2.5 - 11.7	1,200
	Ra-228	2.1 - 15.5	180
Geothermal waters[4]	Total Ra		56
Mineral spring waters[4]	Total Ra		15.5

Preese Hall flowback water[1] (Bq/l)

	14 Apr	3 May	23 May	19 Aug
Th-234	<2.0	<2.0	<2.0	<6.0
Ra-226	14	16	17	90
Pb-214	1.4	6	2.3	50
Bi-214	0.9	5.1	2.1	41
Ac-228	1.7	2.6	2.9	12
Th-228	<4.0	<4.0	<4.0	<10
Ra-224	<4.0	<4.0	<4.0	<4.0
Pb-212	0.4	0.9	0.7	<0.5
Bi-212	<0.5	<0.5	<0.5	<2.0
Tl-208	<0.5	<0.5	<0.5	<0.5
U-235	<0.1	<0.1	<0.1	<0.3
Th-227	<0.5	<0.5	<0.5	<2.0
Ra-223	<0.5	2.1	<0.5	<2.5
K-40	<1.0	3.5	3.3	<3.0

Preese Hall shale gas well flowback water



Volumes and activities

- Current UK onshore oil and gas production [1]
  - 9.3 million m3 of produced water per year
  - Gas fields generate 200 – 8,500 m3 of produced water per million m3 gas (median 1,280 m3 per million m3)
- Estimates of UK shale gas reserves:

Estimated reserves	Produced water	Total activity	
560 billion m^3	700 million m^3	15 – 70 TBq	UK total[2]
5.6 trillion m^3	7 billion m^3	150 – 700 TBq	Bowland Shale under Lancashire[3]

- Short-term issues for management and disposal of flowback from shale gas well development
  - Low reservoir permeability means far more wells required than for conventional gas – all requiring fracking
  - Insufficient radioactive substances Permitted water treatment facilities available to meet demand
  - Experience suggests operators of existing water treatment works reluctant/unwilling to apply for radioactive substances Permit on commercial grounds
- Significant long-term requirement for management of produced water once shale gas wells enter production
  - DECC data incomplete, but all onshore produced water in UK is currently believed to be reinjected

Source: [1]DECC UK Production Data Release, Sept 2012, [2]Energy Information Association 2011, [3]Cuadrilla 2012

Other extractive technologies have similar NORM issues

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- Coal Bed Methane
  - Extraction of large volumes of water to depressurise coal seams, releasing gas
  - 10% of US total gas production in 2008[1]
  - Very great potential in UK - pilot projects under way
  - UK coals have lower permeability than USA – fracking may be required[2]
- Underground Coal Gasification
  - Partial *in situ* combustion of deep coal seams by injection of oxygen and water/steam
  - EU trial demonstrated feasibility at depths of European coal
  - NNL has looked at modelling and assessment of environmental impacts
- Geothermal energy
  - Wells drilled into crystalline basement, 4.5-5km depth
  - Geothermal waters typically have moderate salinity; lower dissolved Ra than oil and gas reservoirs[3]
  - US geothermal industry may generate 1.4 million te of solid NORM waste over next 20 years[4]
  - Successful UK pilot project at Rosemanowes (Cornwall) in 1980s – 2 further projects under way

Source: [1]International Energy Agency, [2]DECC 2010, [3]Battye & Ashman 2008, [4]US EPA

Disposal routes for fracking fluids

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- Storage and disposal are key issues
  - Permit required for storage
  - Spill management and groundwater protection planning
  - Lagoons (lined) or tanks (double skinned or bunded)
- Disposal options:

Permitted water treatment works (municipal or commercial)	• Availability extremely limited • Transportation issues (tanker or pipeline) • Ultimately relies on "treatment" by dilution
On-site treatment + discharge	• Permit required • Creates solid waste stream requiring disposal (could be exempt)
Reinjection in disposal well(s)	• Depends on availability of suitable injection zone • Permit(s) required (not easy to obtain in UK?)
Reuse/recycling of flowback water	• Pre-treatment may be required • Salinity is key issue – reverse osmosis & distillation effective, but energy intensive

- US shale gas industry is driving major boom – market for fracking-related water treatment predicted to grow nine-fold to $US 9 billion/year by 2020[1]
- Potential for temporary centralised treatment facilities during development of shale gas reservoirs

Source: [1]Lux Research 2012

Flow-back fluid transport issues – UK regulatory requirements

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DEFRA 'Guidance on scope of exemptions from radioactive substances legislation in the UK', Guidance Document (Sept 2011 v1)

- Threshold value above which legislation applies for liquid waste of this nature is 1.0 Bq/l

- Flowback water from shale gas typically contains levels of Ra-226 in excess of 1 Bq/l (typically values range from 14-90 Bq/l)
- As such it is classified as a radioactive waste and thus requires regulation and permitting for storage, transport and disposal

Flow-back fluid transport issues – UK regulatory requirements

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Environmental Damage Regulations (2009)

- Implements the European Directive on Environmental Liability – based on the 'polluter pays' principle:
  - Those who undertake activities that may have a negative impact on the environment initially take all reasonable precautions to prevent, and ultimately should it occur, remedy environmental damage rather than the tax payer
- Environmental Damage Regulations apply when:
  - Adverse effects on the integrity of a SSSI or on the conservation status of species and habitats protected by EU legislations outside SSSIs
  - Adverse effects on surface water or groundwater consistent with deterioration in the water's status (Water Framework Directive term)
  - Contamination of land that results in significant risk of adverse effects on human health

Flow-back fluid transport issues – UK regulatory requirements

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Example: Shale gas operator drilling operation

- Environment Agency assessed the potential impact of drilling and hydraulic fracturing operations at a UK operator's drill site and concluded that a Permit was not needed for drilling and fracking.

- This was based on:
    - No vulnerable near-surface aquifers
    - No nearby surface water features such as streams, rivers or lakes
    - No groundwater in or around deep shale formations (shale formations typically have low permeability and would thus not contain 'groundwater' according to the Water Framework Directive and Environmental Permitting Regulations)

BUT…

Flow-back fluid transport issues – UK regulatory requirements

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Transport of flowback water considered as radioactive waste:
Radioactive Materials (Road Transport) Regulations (2002) (as amended)

- Use of commercial road tankers to move waste flowback water considered acceptable to Regulators, subject to determining correct classification (i.e. in terms of applying correct UN number for waste and correct signage etc.)

- Movement of waste would need to be undertaken by contractor/operator licensed to transport radioactive materials

- Contractor would be responsible for determining correct Low Specific Activity Material classification and applying correct UN number

- Clearly there are public perception issues:

- …which can only be avoided by reducing the levels of activity in the waste to exempt levels prior to transport and disposal…
- using onsite treatment prior to disposal or segregation (dilution not permitted!)

Flow-back fluid transport issues – UK regulatory requirements

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Options for reducing levels of activity in wasteto exempt levels prior to transport and disposal

- Segregation of flowback returns
  - Highest activity likely to be within formation water (rather than injected fluid) so initial flowback water is likely to comprise predominantly injected fluid and will thus contain less Ra-226
  - After fracking the rate of fluid production is likely to decrease but activity concentration will increase as the % of formation water in flowback water increases
  - By segregting flowback water, it may be possible to exempt some of the returns from regulatory control and therefore make disposal more cost effective
- On site treatment of flowback water prior to disposal
  - E.g. ion exchange processes to remove Ra-226 prior to disposal
- ...

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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- Based on real worked examples
- Preliminary, qualitative assessment of risk magnitude to environment should NORM-containing flow-back water leak from containment (road tanker) during transport
- Environmental 'receptor' or 'exposure point':
  - surface water
  - groundwater
  - humans
  - flora
  - fauna
- Source➔Pathway➔Receptor pollutant linkage model – if linkage incomplete, no exposure pathway so no risk to environment

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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Method
Consequence and Likelihood Criteria

- Level of risk = combination of magnitude of consequence or hazard posed by impact and likelihood/probability of occurring – development of 'Consequence and Likelihood Criteria':

CONSEQUENCE CRITERIA		
	Consequence Level	**Environmental Impact**
Threat	Catastrophic	Impact with potential for severe long term harm or impact on an area of significance
	Major	Impact resulting in medium to long harm. Localised impacts which are not easily remediated, widespread impacts over a medium term
	Moderate	Impact with localised medium term harm or widespread measurable but minimal harm
	Minor	Impact with the potential to cause local, limited duration harm which can be remediated or widespread negligible harm
	Slight	Single on-site event, causing negligible harm

	LIKELIHOOD CRITERIA
Rating	**Frequency**
Likely	Will occur in most circumstances. Known to occur, or "it has happened"
Possible	Might occur at some time. Could occur or "I've heard of it happening"
Unlikely	Could occur at some time. Not expected to occur
Rare	May occur only in exceptional circumstances. Practically impossible

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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Method
Risk classification matrix and Impact Action Description

- A 6x5 risk matrix was used to asses the overall level of risk to the environment for each pollutant linkage

Likelihood	Consequence					
	Slight	**Minor**	**Moderate**	**Major**	**Catastrophic**	**No data**
Rare	Low	Low	Moderate	Moderate	High	Not classifiable
Unlikely	Low	Moderate	Moderate	High	Very High	
Possible	Low	Moderate	High	Very High	Very High	
Likely	Moderate	High	Very High	Very High	Very High	
No data	Not classifiable					

- Risk rating then assessed for tolerability and need for mitigation measures to be put in place, including changes to operating practice + additional precautions when transporting waste fracking fluid (although we made no recommendations as to the actual mitigation measures that should be implemented) – **Impact Action Description**:

Risk Rating	**Qualitative Risk Action Description**
Low	Broadly acceptable
Moderate	Tolerable but impact should be reduced if reasonably practicable
High	Undesirable – Further mitigation measures are required to reduce the impact to as low as reasonable practicable. To bring target impact to low or moderate
Very High	Unacceptable

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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Exposure Scenarios

- Exposure Scenario = 1 transport activity = transport from drill site to waste water treatment works

- Envisaged that tankers would take the shortest, quickest and safest routes, passing through as few populated areas as possible, whilst ensuring the route is suitable for tankers

- For the sites we examined, routes included minor roads (unclassified, and ‘B’ and ‘A’ [non-trunk] roads), major roads (trunk routes classified as ‘B’ and ‘A’ roads), and motorways

- Case study - generic exposure pathways included:
    - Infiltration and migration of waste flowback water into surface/groundwaters
    - Ingestion and dermal contact,
    - Inhalation of vapours and

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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- Ingestion and dermal contact:
  - If all the water from a spill migrated to a surface water body, dilution of Ra-226 would be significant, but…
  - 1 litre of NORM-contaminated flowback water must be diluted by 9 litres of uncontaminated water in order for the concentration of Ra-226 to be below the WHO drinking water standard of 1 Bq/l
  - Dilution factor of 1 part in 9 readily achievable if flowback water mixes with 1000’s litres in a river or lake
  - Less chance of dilution at driest time of year (e.g. April – August)
  - For ingestion pathway to be significant, a receptor would need to drink water directly from a pool of water next to the tanker spilling the fluid, or from the motorway drainage system during drier months
- Inhalation of vapours
  - Ra-226 decays to Rn-222 gas
  - Surface waterways typically very well ventilated – only human exposure possibility would be inhalation at sump or inspection hatch in motorway surface water drainage system near to where spilled flowback water accumulated
  - Water would have to have been stagnant for up to 19 days to allow maximum Rn-222 build up – extremely unlikely

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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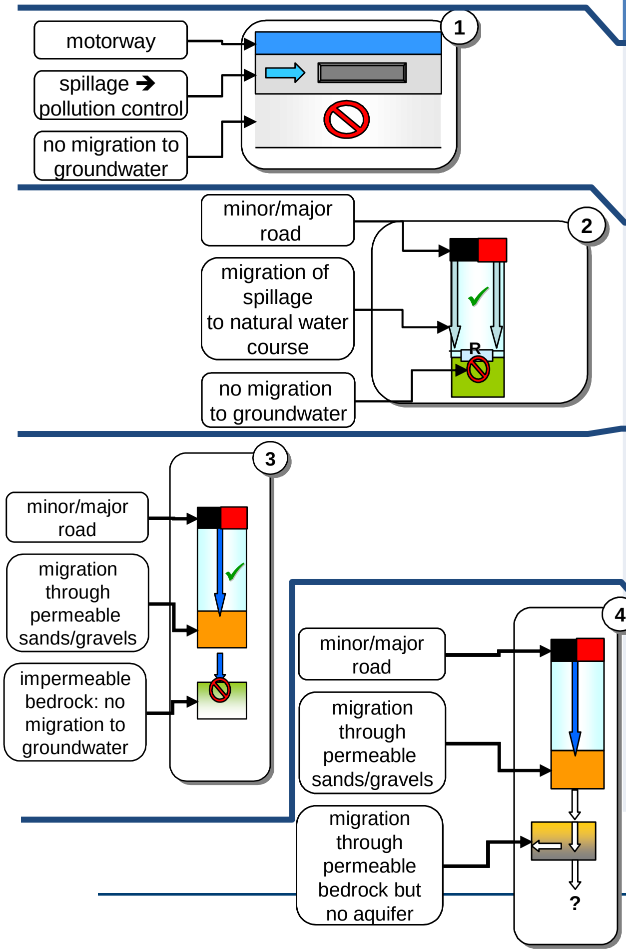
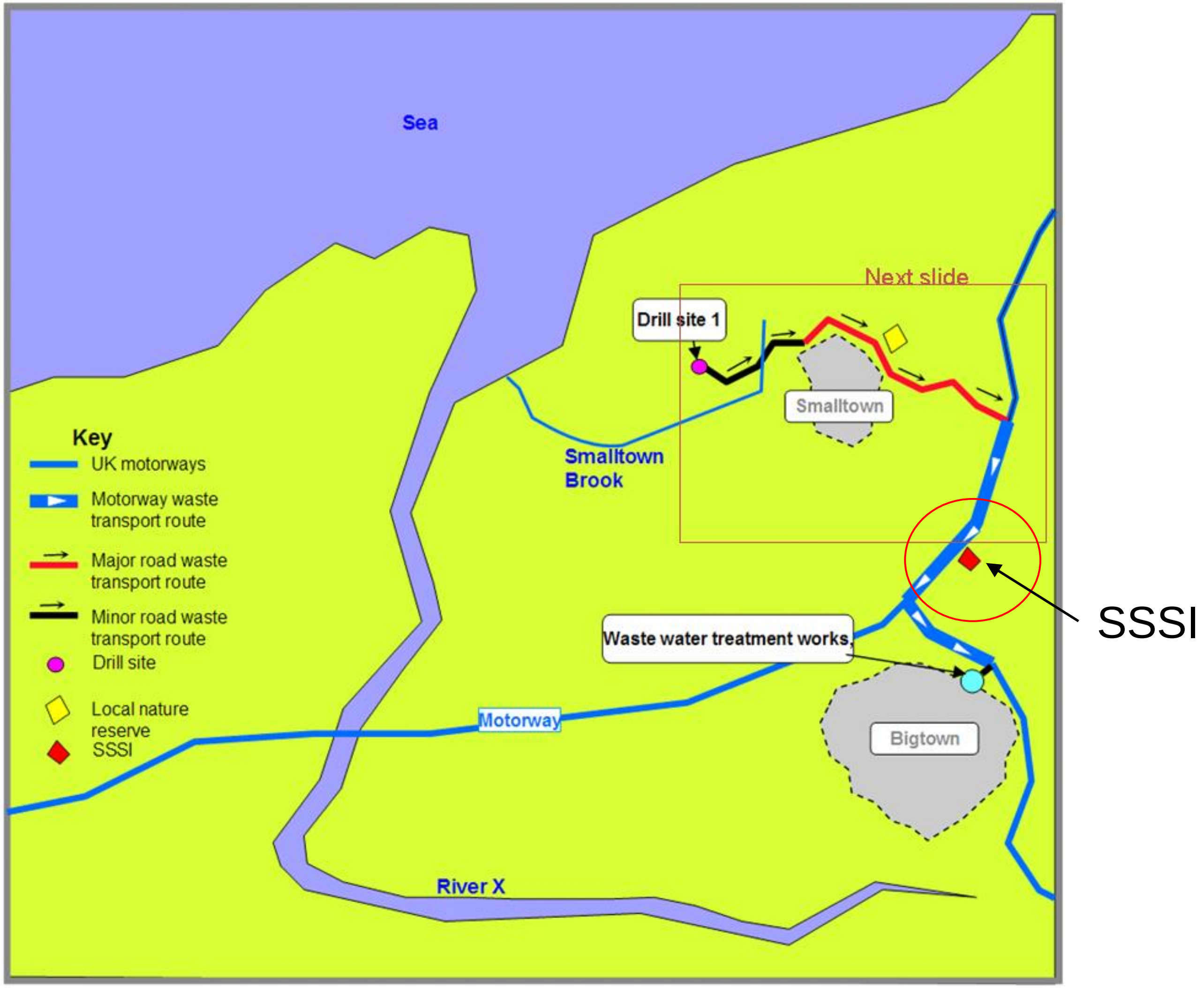
- Infiltration and migration of waste flowback water
  - Governed by permeability of natural or artificial barriers underlying route
  - Minor/major roads - barrier assumed here to be natural (worst case, as some major trunk roads do have engineered spillage control / drainage systems)
  - Motorways – barrier assumed to be engineered



Description of geology	Description of barrier	Permeability	Route to groundwater?
Route does not reach geology	**Engineered:** Man-made motorway drainage & spillage control	Impermeable	No route to superficial geology no route to groundwater
Superficial geology: glacial till (clay rich) on mudstone bedrock	**Natural:** Impermeable clay	Impermeable	Route to (but not through) superficial geology No route to bedrock and bedrock aquifer
Superficial geology: glacial sands and gravels on mudstone bedrock	**Natural:** Impermeable mudstone bedrock	Impermeable	Route through superficial geology Bedrock impermeable – no route to aquifer
Superficial geology: glacial sands and gravels on bedrock comprising Carboniferous coal measures	**None**	Permeable	Route through superficial geology to permeable bedrock. No aquifer present

Case study - Environmental risk associated with transport of NORM contaminated flowback water



(nb – location map not a real place!)

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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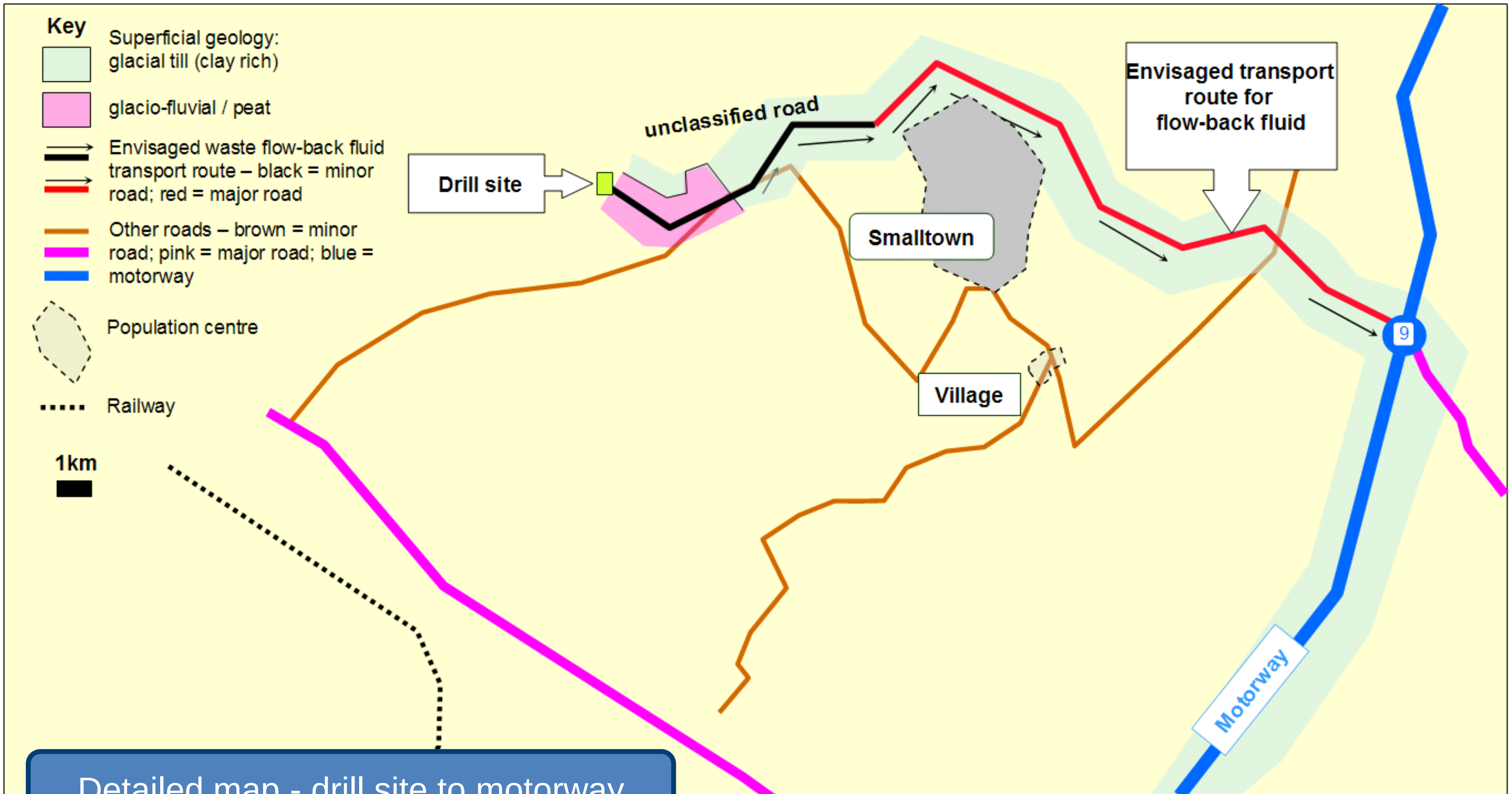

Detailed map - drill site to motorway

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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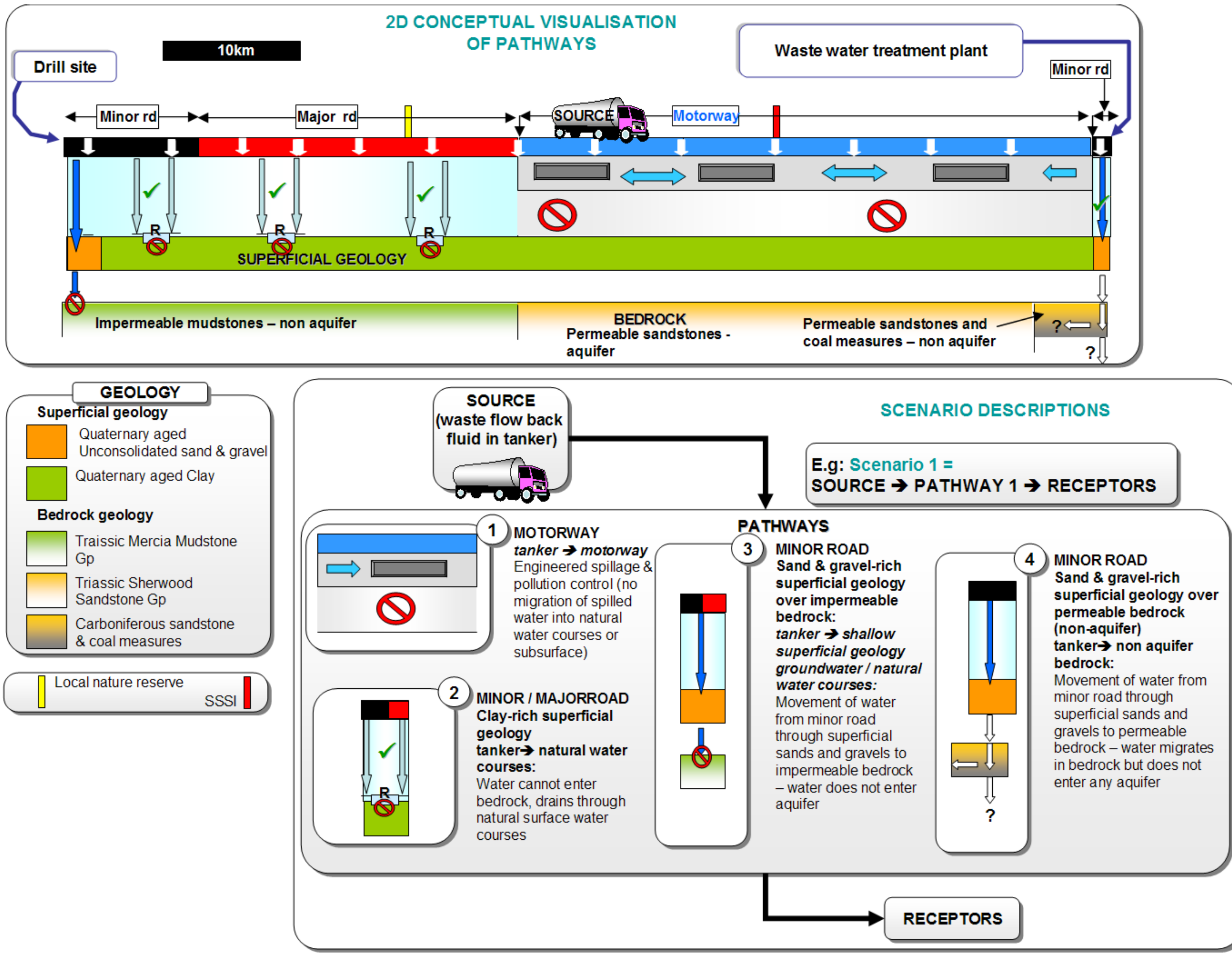

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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Potential pollutant linkages from a spill during transport of waste flowback water from drill site to waste treatment works

Source	Pathways	Receptors	Likelihood	Consequence	Risk Ranking
Spilt waste fracking fluid	Dermal contact and ingestion	Motorists on roads and motorways	Possible	Minor	Moderate
Spilt waste fracking fluid	Dermal contact and ingestion	Police attending site of accident	Possible	Minor	Moderate
Spilt waste fracking fluid	Dermal contact and ingestion	Rescue services attending site of accident	Possible	Minor	Moderate
Spilt waste fracking fluid	Dermal contact and ingestion	Staff and residents in residential areas	Unlikely	Minor	Moderate
Spilt waste fracking fluid	Transport through surface water drainage system and direct run-off	Surface water in Smalltown Brook	Possible	Minor	Moderate
Spilt waste fracking fluid	Transport through surface water drainage system and run-off	Surface Water SSSI	Possible	Moderate	High
Spilt waste fracking fluid	Direct contact and ingestion	Flora and Fauna at SSSI	Possible	Major	Very High
Contaminated surface water	Direct contact and ingestion	Flora and Fauna at SSSI	Possible	Moderate	High

Case study - Environmental risk associated with transport of NORM contaminated flowback water

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- Risk of flowback water containing Ra-226 entering surface/groundwater is relatively low, but…
- Several complete potential pollutant linkages resulting from spillage of waste flowback water which could contain Ra-226.
- In this case study, environmental risks associated with these pollutant linkages are moderate to high (SSSI along the transport route has a ‘high’ risk ranking). Whilst moderate risks are tolerable but should be reduced, a high risk is unacceptable
- Regulations indicate that these risks need to be allowed for when planning and undertaking transport of waste flowback water potentially containing levels of Ra-226 above the WHO drinking water standard of 1 Bq/l
- Additionally regulatory guidance indicates that if levels are above this, the fluid is classed as radioactive and tankers must therefore display required signage – which is a clear public perception issue!

- Alternatively, shale gas operators must undertake mitigating operations to reduce the level of Ra-226 prior to transport of the waste flowback water

Thank you

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