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Deep Geological Storage of CO₂ on the UK Continental Shelf: Containment Certainty

Supplementary Note A: Breakdown of
Combined Well and Geological Storage Risks
for Typical Storage Sites

February 2023



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This note is supplementary to the report “Deep Geological Storage of CO₂ on the UK Continental Shelf: Containment Certainty”, and other associated supplementary notes. It is aimed at a technically experienced scientific audience.

The purpose of this Supplementary Note is to provide further detailed tables showing how the leakage risks have been combined for both mechanical and geological pathways, to derive indicative overall risks for ‘typical’ permitted CCS storage sites that could be commissioned for the UK Continental Shelf (UKCS).

The different leakage pathways are defined and further described in the main report and other Supplementary Notes. Tables in this note combine the probabilities of occurrence, reasonable worst case leakage rates and durations per feature, and an estimate of typical numbers of features for typical sites, to derive a risked estimate of the minimum contained amount of CO₂. These numbers underpin the values given in Table 20 in the main report. For discussion of the significance of these tables please see either the corresponding supplementary note or the main report.

The probability of any leakage event occurring from a UKCS storage site that has been granted a storage permit is inherently low. To understand the combined total significance of these different potential leakage events for a store, it is necessary to combine probability of occurrence for the different leakage pathways. To provide an illustration of how geological and well leaks could combine to produce an overall view on the total amount and probability of leaks during the operational and post-closure period, two ‘typical’ storage complexes have been conceived and overall containment probabilities derived. Parameters were chosen to reflect realistic values for ‘typical’ depleted oil and gas fields and confined saline aquifer sites, and to allow evaluations of risk to be scaled-up easily for future sites that contain varying numbers of specific leakage pathways. For ease of comparison, the typical depleted fields and confined aquifers are defined to have the same overall parameters where reasonable, except where characteristic differences between the two are likely to exist for permitted sites (e.g. size of monitoring area, the number of decommissioned wells and faults, brine production wells).

Parameters used to estimate leakage risk for typical depleted field and fully and partially confined saline aquifer CO₂ stores on the UK Continental Shelf (UKCS).

Parameter	Depleted Field	Confined Saline Aquifer	Impact in calculation of containment risks per feature or in a typical site
Storage Capacity (Mt)	125	125	Used when calculating minimum % of store capacity expected to be contained during operations + 100 years
Depth (m)	2500	2500	Used in Peloton (failure frequency given per km of well)
Area (km ²)	100	150	Not used in this analysis (would have impact on seismic monitoring costs)
Number of Active Wells	5	5	Used in assessment of active well risk
Number of Monitoring wells	1	1	Used in assessment of active well risk
Number of Brine Producing Wells	0	2	Used in assessment of active well risk
Injection Rate per well (Mtpa)	1	1	Used to constrain the number of wells for capacity and duration of the site.
Number of Legacy Wells	5	2	Used for inactive well risk. Likely to be more in depleted field.
Years of Injection Operations	25	25	Multiplier for per annum well risks
Years Post-Closure	100	100	Multiplier for inactive well risks after CO ₂ injection operations have ceased
Caprock thickness (m)	400	400	Used in derivation of potential leakage rates for through caprock risk
Number of large block-bounding fault zones	1	0	Assumed unlikely to be present in permitted UKCS saline aquifer site, but could be present in depleted field
Number of map-scale faults	4	0	Assumed unlikely to be present in permitted UKCS saline aquifer site, but could be present in depleted field

Notes:

Well leakage rates are more accurately measured than geological leaks. Many sources on leakage rates from wells are quoted in tonnes per day, whereas geological leakage rates are less accurately measured and stated in tonnes per year. Numbers in the tables that are derived by converting between rates per year and per day may be reported with multiple decimal places; this is to make the derivation of the numbers clear, and does not imply either correspondingly high precision or accuracy in the stated values.

Overall Depleted Oil or Gas Field Storage Site Results		Results per feature					Results applied to 'typical' Depleted Field site													
		Leak category (and pathway sub-mechanism)		Probability of occurrence [A]		Context of probability estimate	Leak rate (tonne/day) [B]		Duration (years/event) [C]	Total Loss (tonnes)/event [D=B*365*C]		Maximum % Store Volume per event [D / 125Mt %]	Number of items/features during operating period (25 years) [E]	Number of items/features during closure period (100 years) [E]	Overall Probability of event during Operations + 100 years [F=E*A] or [F=Σ(E*A*(25 or 100))]		Risky estimate of amount leaked during Operations + 100 years* (Tonnes) [G=F*D]		Estimated risky maximum leakage amount as % of Store Capacity** [H=G / 125Mt %]	Estimated risky minimum contained amount as % of store capacity** [100%-H]
				max	min		max	min		max	min				max	min	max	min		
Active Wells including Monitoring Wells	Seep	1.00E-01	1.00E-03	per well	1	0.1	25.00	9125.00	912.50	0.0073%	6	0	6.00E-01	6.00E-03	5475.00	5.48	0.004%	99.996%		
	Minor	1.00E-03	1.00E-05	per well per annum	50	1	0.50	9125.00	182.50	0.0073%	6	0	1.50E-01	1.50E-03	1368.75	0.27	0.001%	99.999%		
	Moderate	1.00E-04	1.00E-05	per well per annum	1000	50	0.33	121666.67	6083.3	0.0973%	6	0	1.50E-02	1.50E-03	1825.00	9.13	0.001%	99.999%		
	Major	1.00E-05	1.00E-06	per well per annum	5000	1000	0.33	608333.33	121667	0.4867%	6	0	1.50E-03	1.50E-04	912.50	18.25	0.001%	99.999%		
Inactive Wells	Seep	1.00E-01	1.00E-03	per well	1	0.1	125.00	45625.00	4562.50	0.0365%	5	11	1.10E+00	1.10E-02	44712.50	44.71	0.036%	99.964%		
	Minor	1.00E-03	1.00E-04	per well per annum	50	1	0.50	9125.00	182.50	0.0073%	5	11	1.23E+00	1.23E-01	11178.13	22.36	0.009%	99.991%		
	Moderate	1.00E-04	1.00E-05	per well per annum	1000	50	0.33	121666.67	6083.3	0.0973%	5	11	1.23E-01	1.23E-02	14904.17	74.52	0.012%	99.988%		
	Major	1.00E-05	1.00E-06	per well per annum	5000	1000	0.33	608333.33	121667	0.4867%	5	11	1.23E-02	1.23E-03	7452.08	149.04	0.006%	99.994%		
Through caprock	diffusion	negligible for UKCS		10x10m area, after 1,000,000 years	2.74E-06	2.74E-08	0	0.00	0.00	0.0000%	0	0	0	0	0.00	0.00	0.000%	100.000%		
	capillary flow through intact caprock	negligible for UKCS		for 10x10m area, after 1,000 years	2.74E-05	2.74E-09	0	0.00	0.00	0.0000%	0	0	0	0	0.00	0.00	0.000%	100.000%		
	lateral variability in caprock lithology	negligible for DOGF in UKCS		for 1x1km area, after 100 years	43.0	4.3	0	0.00	0.00	0.0000%	0	0	0	0	0.00	0.00	0.000%	100.000%		
Faults (and fractures)	major tectonically/volcanically active fault zone	negligible for UKCS		per fault zone	5479	27.4	0	0.00	0.00	0.0000%	0	0	0	0	0.00	0.00	0.000%	100.000%		
	large block-bounding fault zone	Minor	1.00E-04	1.00E-05	per fault zone	2.7	2.7	25	25000	25000	0.0200%	1	1	1.00E-04	1.00E-05	2.50	0.25	0.000%	100.000%	
	map-scale faults	Seep	1.00E-03	2.74E-04	per fault zone	1.0	0.27	100	36525	10000	0.0292%	4	4	4.00E-03	1.10E-03	146.10	10.96	0.000%	100.000%	
		Minor	2.74E-04	1.00E-04		2.7	1.0	100	100000	36525	0.0800%			1.10E-03	4.00E-04	109.59	14.61	0.000%	100.000%	
	sub-seismic scale faults & fracture network	Seep	2.50E-03	2.02E-04	per site	1.0	0.027	100	36525	1000	0.0292%	1	1	2.50E-03	2.02E-04	91.31	0.20	0.000%	100.000%	
Minor		2.02E-04	1.00E-04	2.7		1.0	100	100000	36525	0.0800%	2.02E-04			1.00E-04	20.23	3.65	0.000%	100.000%		
Induced faulting/fracturing	reactivation of pre-existing faults	Seep	1.00E-03	5.23E-04	per site	1.0	0.27	100	36525	10000	0.0292%	1	1	1.00E-03	5.23E-04	36.53	5.23	0.000%	100.000%	
		Minor	5.23E-04	1.00E-04		27.4	1.0	100	1000000	36525	0.8000%			5.23E-04	1.00E-04	523.42	3.65	0.000%	100.000%	
	initiation of new faults/fractures	Seep	1.00E-03	5.23E-04	per site	1.0	0.27	100	36525	10000	0.0292%	1	1	1.00E-03	5.23E-04	36.53	5.23	0.000%	100.000%	
		Minor	5.23E-04	1.00E-04		27.4	1.0	100	1000000	36525	0.8000%			5.23E-04	1.00E-04	523.42	3.65	0.000%	100.000%	
Gas chimneys/pipes	Seep	2.50E-03	2.66E-04	per feature	1.0	0.1	100	36525	3653	0.0292%	1	1	2.50E-03	2.66E-04	91.31	0.97	0.000%	100.000%		
	Minor	2.66E-04	1.00E-04		2.7	1.0	100	100000	36525	0.0800%			2.66E-04	1.00E-04	26.64	3.65	0.000%	100.000%		
Lateral Migration	Seep	2.67E-03	6.30E-04	Very site specific. Averaged geological risks used to derive notional values.	1.0	0.027	100	36500	1000	0.0292%	1	1	3.67E-03	9.04E-04	133.83	0.90	0.000%	100.000%		
	Minor	6.30E-04	1.70E-04		27.4	1.0	25	250000	9125	0.2000%			9.04E-04	2.70E-04	225.95	2.46	0.000%	100.000%		
Total															89,795*	379	0.072%	99.928%		

* of a total injected amount of 125,000,000 tonnes of CO₂

** duration is 25 years injection + 100 years

Overall Confined Saline Aquifer Storage Site Results		Results per feature					Results applied to 'typical' Confined Saline Aquifer site													
		Leak category (and pathway mechanism)		Probability of occurrence [A]		Context of probability estimate	Leak rate (tonne/day) [B]		Duration (years/event) [C]	Total Loss (tonnes)/event [D=B*365*C]		Maximum % Store Volume per event [D / 125Mt %]	Number of items/features during operating period (25 years) [E]	Number of items/features during closure period (100 years) [E]	Overall Probability of event during Operations + 100 years [F=E*A] or [F=Σ(E*A*(25 or 100))]		Risky estimate of amount leaked during Operations + 100 years* (Tonnes) [G=F*D]		Estimated risky maximum leakage amount as % of Store Capacity** [H=G / 125Mt %]	Estimated risky minimum contained amount as % of store capacity** [100%-H]
				max	min		max	min		max	min				max	min	max	min		
Active Wells including Monitoring Wells	Seep	1.00E-01	1.00E-03	per well	1	0.1	25.00	9125.00	912.50	0.0073%	8	0	8.00E-01	8.00E-03	7300.00	7.30	0.006%	99.994%		
	Minor	1.00E-03	1.00E-05	per well per annum	50	1	0.50	9125.00	182.50	0.0073%	8	0	2.00E-01	2.00E-03	1825.00	0.37	0.001%	99.999%		
	Moderate	1.00E-04	1.00E-05	per well per annum	1000	50	0.33	121666.67	6083.33	0.0973%	8	0	2.00E-02	2.00E-03	2433.33	12.17	0.002%	99.998%		
	Major	1.00E-05	1.00E-06	per well per annum	5000	1000	0.33	608333.33	121667	0.4867%	8	0	2.00E-03	2.00E-04	1216.67	24.33	0.001%	99.999%		
Inactive Wells	Seep	1.00E-01	1.00E-03	per well	1	0.1	125.00	45625.00	4562.50	0.0365%	2	10	1.00E+00	1.00E-02	38325.00	38.33	0.031%	99.969%		
	Minor	1.00E-03	1.00E-04	per well per annum	50	1	0.50	9125.00	182.50	0.0073%	2	10	1.05E+00	1.05E-01	9581.25	19.16	0.008%	99.992%		
	Moderate	1.00E-04	1.00E-05	per well per annum	1000	50	0.33	121666.67	6083.33	0.0973%	2	10	1.05E-01	1.05E-02	12775.00	63.88	0.010%	99.990%		
	Major	1.00E-05	1.00E-06	per well per annum	5000	1000	0.33	608333.33	121667	0.4867%	2	10	1.05E-02	1.05E-03	6387.50	127.75	0.005%	99.995%		
Through caprock	diffusion	negligible for UKCS		10x10m area, after 1,000,000 years	2.74E-06	2.74E-08	0	0.00	0.00	0.0000%	0		0	0	0.00	0.00	0.000%	100.000%		
	capillary flow through intact caprock	negligible for UKCS		for 10x10m area, after 1,000 years	2.74E-05	2.74E-09	0	0.00	0.00	0.0000%	0		0	0	0.00	0.00	0.000%	100.000%		
	lateral variability in caprock lithology	5.00E-03	5.00E-04	for 1x1km area, after 100 years	43.0	4.3	10	2.36E+06	2.36E+05	1.8847%	1		5.00E-03	5.00E-04	11,779	117.79	0.009%	99.991%		
Faults (and fractures)	major tectonically/volcanically active fault zone	negligible for UKCS		per fault zone	5479	27.4	0	0.00	0.00	0.0000%	0		0	0	0.00	0.00	0.000%	100.000%		
	large block-bounding fault zone	Minor	1.00E-03	5.00E-04	per fault zone	1370	2.7	25	12,500,000	25,000	10.0000%	0		0	0	0	0.00	0.000%	100.000%	
	map-scale faults	Seep	1.00E-02	5.23E-03	per fault zone	1.0	0.27	100	36525	10000	0.0292%	0		0	0	0	0.00	0.000%	100.000%	
		Minor	5.23E-03	1.00E-03		27.4	1.00	100	1000000	36525	0.8000%	0		0	0	0	0.00	0.000%	100.000%	
	sub-seismic scale faults & fracture network	Seep	1.25E-02	3.35E-03	per site	1.0	0.027	100	36525	1000	0.0292%	1		1.25E-02	3.35E-03	457	3.35	0.000%	100.000%	
Minor		3.35E-03	1.00E-03	27.4		1.00	100	1000000	36525	0.8000%	1		3.35E-03	1.00E-03	3,355	36.53	0.003%	99.997%		
Induced faulting/fracturing	reactivation of pre-existing faults	Seep	1.00E-02	5.23E-03	per site	1.0	0.27	100	36525	10000	0.0292%	1		1.00E-02	5.23E-03	365	52.34	0.000%	100.000%	
		Minor	5.23E-03	1.00E-03		27.4	1.00	100	1000000	36525	0.8000%	1		5.23E-03	1.00E-03	5,234	36.53	0.004%	99.996%	
	initiation of new faults/fractures	Seep	1.00E-02	5.23E-03	per site	1.0	0.27	100	36525	10000	0.0292%	1		1.00E-02	5.23E-03	365	52.34	0.000%	100.000%	
		Minor	5.23E-03	1.00E-03		27.4	1.00	100	1000000	36525	0.8000%	1		5.23E-03	1.00E-03	5,234	36.53	0.004%	99.996%	
Gas chimneys/pipes	Seep	1.00E-02	3.00E-03	per site	1.0	0.100	100	36525	3653	0.0292%	1		1.00E-02	3.00E-03	365	10.97	0.000%	100.000%		
	Minor	3.00E-03	1.00E-03		8.2	1.000	100	300000	36525	0.2400%	1		3.00E-03	1.00E-03	901	36.53	0.001%	99.999%		
Lateral Migration	Seep	1.75E-02	5.40E-03	Very site specific. Averaged geological risks used to derive notional values.	1.0	0.027	100	36500	1000	0.0292%	1		1.42E-02	5.61E-03	517.08	5.61	0.000%	100.000%		
	Minor	5.40E-03	1.83E-03		27.4	1.0	25	250000	9125	0.2000%	1		5.61E-03	1.33E-03	1402.32	12.17	0.001%	99.999%		
															Total	109,819*	694	0.088%	99.912%	

^ assumes 10% of area of storage site has lower quality caprock that is reached by the CO₂ plume

* of a total injected amount of 125,000,000 tonnes of CO₂

** duration is 25 years injection + 100 years

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