Review of offshore CO_2 storage monitoring: operational and research experiences of meeting regulatory and technical requirements

Sarah Hannis[1] Andy Chadwick[1] Doug Connelly[2] Jerry Blackford[3] Tim Leighton[4] Dave Jones[1] Jonathan Pearce[1] Jim White[1] Paul White[4] Ian Wright[2] Steve Widdicombe[3] James Craig[5] Tim Dixon[5]

[1]British Geological Survey, Nottingham, NG12 5GG, UK

[2]National Oceanography Centre, Southampton, SO14 3ZH, UK

[3]Plymouth Marine Laboratory, Plymouth, PL13DH, UK

[4]University of Southampton, Southampton, SO17 1BJ, UK

[5]IEAGHG, Cheltenham, GL51 6SH, UK

Abstract

The world's first large-scale dedicated CO_2 storage operation commenced at the Sleipner gas field in the Norwegian North Sea in 1996; this was followed by the Snøhvit project, in 2008. There are plans for up to three more large-scale storage projects in the North Sea Basin: Goldeneye and White Rose in the UK and ROAD in the Netherlands; and a pilot-scale project in Japan. If these come to fruition then near-term rollout of full-chain CO_2 storage will be predominantly offshore. A review the issues surrounding the monitoring of large-scale offshore storage is therefore documented in a publically available report from IEAGHG (released Q1 2016).

Dedicated storage regulation was initiated by amendments to the London Protocol and the OSPAR Convention in 2007 which put in place for the first time the legislative means for storing CO_2 beneath the seafloor. This was followed by publication of the European Storage Directive in 2009. Sleipner and Snøhvit both pre-date this, so the interaction of operational monitoring practice with regulatory requirements has yet to be tested. Offshore storage regulations also exist and are developing elsewhere, notably in Japan, Australia and the United States. The regulatory documents from the different national jurisdictions all emphasise the key role of monitoring and the range of objectives it should serve. These can be broadly distilled as demonstrating that the storage site is performing effectively and safely and that it will continue to do so into the future. This approach can therefore be expressed as providing assurance of containment and conformance.

Monitoring can be split into two main categories: deep-focussed (providing surveillance of the reservoir and deeper overburden) and shallow-focussed (providing surveillance of the near seabed, seabed and water-column).

Deep-focussed operational monitoring systems have been deployed for a number of years at Sleipner, Snøhvit and also at the pilot-scale K12-B project in the offshore Netherlands, and conclusions regarding the efficacy of key technologies are starting to emerge. Time-lapse 3D streamer seismics have proved strikingly effective at both large scale storage sites, providing strong capabilities for conformance and containment assurance. At K12-B downhole pressure also proved to be the key tool

for conformance history-matching. A number of deep-focussed research monitoring tools have been deployed at Sleipner and K-12B. Of these, seabed gravimetry has so far perhaps shown the most promise, providing indications of natural complementarity with the seismics in providing preliminary constraints on amounts of CO_2 dissolution at Sleipner.

No operational shallow-focussed monitoring has been yet been deployed offshore, but this will change once new regulated projects come on stream. Extensive research deployments of shallow monitoring systems at both Sleipner and Snøhvit encountered normal seabed conditions throughout. Many tools for the detection of shallow leakage and CO_2 emission at the seabed have been tested at both natural and artificial emission sites. These fall into three categories, geophysical, chemical and biological. The former principally comprise variants of sonar/echosounding and aim either to detect changes of seabed morphology and reflectivity in time-lapse mode, or to directly detect bubble-streams in the water column. Chemical sampling methods aim to detect and characterise changes in the shallow sediments or seawater column due to emitted CO_2 or precursor fluids from the subsurface. Biological methods examine changes in the ecosystem which may occur in response to changes in CO_2 emissions but are still in their infancy and reliable, practical methods have yet to be developed.

Natural variation is a key issue for shallow monitoring and properly characterised baseline datasets are essential to capture naturally-occurring spatial and temporal variation. Stationary monitoring systems deployed on the seabed via landers have the potential for tracking time dependent changes over periods of several months or more. This is sufficient to capture key seasonal changes, but longer-term variability might need multi-year survey campaigns. Onshore, the value of baselines has been proven in refuting leakage allegations.

Based on an assessment of the results from both the monitoring activities from the operational and planned sites, we can outline a generic monitoring approach for offshore storage. The monitoring plan would comprise a 'core' element designed to meet the regulatory requirements of a site that performs as expected throughout its history and a 'contingency' component held in reserve to address any unexpected behaviour that might occur. It is anticipated that a relatively small number of key tools should suffice for the 'core' monitoring element and simplicity should be the byword. The 'contingency' monitoring portfolio might include a more specialised toolset.

It is instructive to compare the different aspects of offshore monitoring with onshore equivalent practice. Deep-focussed monitoring systems have much in common, though with different logistical and technical issues. Some techniques, notably time-lapse seismics, can be compromised by near-surface complexity onshore. On the other hand downhole tool deployments are much more logistically complex and expensive offshore which might lead to a lower emphasis on downhole monitoring. Issues connected with shallow monitoring differ markedly from the offshore to the onshore. Logistics and difficulty of access characterise the offshore and particular issues, such as trawler damage, constrain what can be achieved in terms of permanent monitoring installations. Offshore, it is possible to use active and passive sonar to characterise gas leaks (active sonar to visualise the location, extent and shape of bubble plumes and passive sonar to quantify gas flux through the acoustic emissions made when bubbles are formed), whereas onshore, near surface hydrogeological complexity and surface infrastructure can render leakage and emissions monitoring very challenging.

Monitoring for leakage and emissions still has significant challenges, notably in establishing systems providing robust spatial coverage for reliable emissions detection, and also in the accurate quantification of such emissions. Wellbore integrity is also still a significant issue, particularly the ability to assess and monitor plugged and abandoned wellbores which cannot be readily accessed. Other more generic challenges remain, notably in data transmittal for real time monitoring, power supply and consumption for remotely operated monitoring platforms, and in the general reduction of monitoring costs and its environmental impacts.