IMAGE: courtesy the Sirius Group

Predicting Ground-gas Risk

NICOLA HARRIES, Project Director at CL:AIRE, reports on some of the latest research and developments in contaminated-land remediation, including a special case study on new ground-gas monitoring technology.

One of CL:AIRE's core objectives is to demonstrate the application of technologies that may offer improved site-investigation techniques, monitoring or remediation solutions. In order to meet this objective, CL:AIRE has developed a process in which technology demonstration and research projects are submitted, evaluated by a team of independent experts and – if approved – monitored and reported so that the industry as a whole can benefit from the results.

The CL:AIRE Technology and Research Group (TRG) evaluates each project against the following criteria:

- Scientific validity of the application;
- Robust nature of the methodology;
- Contribution to the UK contaminated-land marketplace;
- Suitable assessment of site criteria;
- Competencies in forms of project management.

CL:AIRE is recognised as an important player in delivering both technology demonstrations and technology research. Indeed, the Department for Communities and Local Government (DCLG) requires that the Regional Development Agencies engage CL:AIRE on all major regeneration schemes that involve remediation. Similarly, the Research Councils recognise the value of CL:AIRE's dissemination programme to UK research.

BENEFITS OF APPROVAL

CL:AIRE supports a broad range of research interests into the characterisation, monitoring and remediation of contaminated land. However, within these three categories there are key areas of research that CL:AIRE ranks highly. These vary from insitu analysis tools which deliver real-time (or near real-time) data – see case study below, to statistical methods to validate environmental sampling protocols, as well as the more traditional remedial technology development.

The three main benefits of having a project approved by CL:AIRE are, firstly, the added value created by the CL:AIRE TRG which provides independent evaluation of projects; secondly, market recognition of this peer-review process; and thirdly, global dissemination of the project. To date, CL:AIRE has facilitated 44 innovative technology demonstration and research projects across the UK with the involvement of over 90 organisations. Once a project is complete, information is shared with all sectors of the contaminated-land community, to provide confidence in new technologies and to inform and improve best practice in the UK.

CASE STUDY: CL:AIRE TECHNOLOGY DEMONSTRATION PROJECT TDP 22

Introduction

This feature section will describe the development of an innovative gas-monitoring technology that is an approved CL:AIRE Technology Demonstration Project (TDP 22).

Improved Ground-Gas Risk Prediction Using In-Borehole Gas Monitoring (IRP-IGM) is a project funded through the Technology Strategy Board's Technology Programme that began in November 2006 and will run until November 2008. It is an industry/university research collaboration between Salamander, Urban Vision and The University of Manchester.

The project has included the development of Gasclam® by Salamander, an in-borehole continuous gas monitor (IGM) that allows a new methodology for monitoring, predicting and quantifying the risk of ground-gas generation and migration. Gasclam® recently won the Innovative Technology (Environmental Technologies) prize at the Northwest Business Environment Awards 2007.

Background

Improved Ground-Gas Risk Prediction using In-Borehole Gas Monitoring (IRP-IGM) by Peter Morris, University of Manchester, Mark Todman, Urban Vision Partnership Ltd and Stephen Boult, University of Manchester and Salamander Ltd.

Flaws in the existing approach to quantifying and predicting risk arising from ground-gas are identified explicitly in the literature (*Wilson & Card, 1999*) and are implicit in the continuing evolution of guidance notes (eg CIRIA). The underlying cause of flaws that exist even in the preferred 'rational approach' (*Wilson & Card, 1999*) is that whilst accurate quantification of existing risk should require accurate measurement of ground-gas concentration and of ground-gas fluxes, neither is measured directly and both are likely to be temporally variable.

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cont.. At present, best practice has effectively been defined by the capability of the available technology for field measurement of ground-gas concentration, however, advances in sensor technology now suggest improvements can be made. The use of miniature infra-red (IR) sensors in an instrument can allow it to be deployed unmanned for extended periods, as its power requirements will be low and it can be small enough to be secured within a borehole. Such a device allows for the collection of concentration data at much higher time resolution than previously possible – this in turn has the potential to reduce errors arising from both the indirect nature and the temporal variability of the measurement.

Measurement is indirect because ground-gas concentration is inferred from periodic sampling of gas accumulated within a borehole and flux is then inferred from these borehole gas concentrations. The relationships these inferences are based on will be highly site-specific and time dependent. Consequently, these measurements are only useful in association with a site-specific conceptual model, the production of which is a requirement of a well executed risk assessment. Typically, conceptual models are made by characterising both the source material for gas and the geological setting, rather than directly characterising the gas production of the site. Gas measurements are then made in a subsequent monitoring programme and interpreted in the context of the conceptual model.

If measurement at high temporal resolution was economically viable, characterisation of gas production could form part of the conceptual model and a monitoring programme could be devised in which sampling frequency and gas variability were optimally matched.

The initial objective of the project was, therefore, to produce an in-borehole gas-monitoring device (IGM) that meets practical, customer and legislative requirements – specifically, security, cost, ease of use and ATEX certification (European Union ATEX Directive 94/9/EC – from the french ATmospheres EXplosibles). Long-term tests, in which the sampling interval varies, will be used to identify the degree to which:

- Concentrations measured in boreholes may be artefacts of the sampling regime;
- Maximum and average concentrations derived from periodic concentration measurements may be inaccurate.

Short-term tests of the IGM will then determine whether pump tests to characterise gas production are practical in the context of the development of conceptual models.

The time series data of ground-gas concentration collected to meet these objectives, accompanied by atmospheric-pressure measurements; the novelty of such data also provides an opportunity to make some observations about the processes of ground-gas migration.

IGM Production

The IGM (Gasclam® www.gasclam.co.uk), pictured above right, is manufactured from stainless steel, ATEX certified and ingress protection rated IP-68. It measures methane, carbon dioxide, oxygen and hydrogen sulphide concentrations, also atmospheric pressure, borehole pressure and temperature. The IGM fits within a borehole securely, whilst it also allows for controlled venting of the borehole. Sampling frequency is variable from 15 seconds to daily, and this is set and data downloaded through a Notebook PC. It can be powered for three months by two alkaline D-cells.

Long-term Continuous Monitoring

Collection of more highly time-resolved data allows the production of meaningful 'concentration duration curves', analogous to hydrological flow duration curves, these provide a more direct interpretation of risk than available from conventional monitoring. The value of continuous measurement is best shown by comparing concentration duration curves from the full Gasclam® dataset from boreholes at test sites (Site A and Site B) with ones from subsets of points that would have resulted from the conventional periodic weekly sampling. Two such subsets are shown in **Figure** 2 overleaf.

Higher temporal resolution, not only of gas concentration but also other environmental variables, allows their inter-relationships to be more clearly defined. This in turn allows dominant controls on gas concentration to be recognised and for better prediction of gas concentration as other parameters change. Atmospheric pressure is considered to be a strong driving force for gas migration (*Wilson et al, 2008*), in general it is assumed that concentrations are higher when pressure is low and vice versa. Current guidance (eg CIRIA Report 665) recommends collecting at least one spot sample below 1000mbar in falling pressure. Continuous monitoring data from Site A, has the expected relationship between pressure and concentration (**see Figure 3** over). However, the arbitrary nature of the 1000mbar limit is clear as concentration continues to vary depending on changes in atmospheric pressure, rather than displaying a clear dependency on the absolute atmospheric pressure (**see Figure 3** over).

Furthermore, the widely reported relationship between pressure and concentration (**see Figure 3** over) does not always exist; the inverse relationship is observed at a neighbouring borehole on Site A (**see Figure 4** over). This further demonstrates the need to characterise gas production in each borehole in order to quantify risk.

The capability of Gasclam® to allow monitoring intervals to be varied with no resource implication both demonstrates the existence of, and offers a way of controlling, artefacts in monitored data. At Site A, prior to the installation of the continuous monitor (Gasclam®), CH4 was frequently observed at low concentrations during conventional spot sample monitoring. However, one month of continuous monitoring shows the CH4 concentration decreasing from 1.5 per cent v/v to 0.0 per cent v/v after two days (**see Figure 5** over).

The discrepancy between the two sampling techniques indicates the measured concentration might be an artefact of the sampling regime. During spot sampling the borehole is sealed between each visit and will act as a collection point allowing gas concentrations to build up between sampling. On this occasion, the continuous monitoring data was recorded in venting mode, which allows gas to pass through as opposed to collecting, giving a more dynamic and representative observation of the true gas regime.

IMAGE: The IGM is now produced commercially and marketed as Gasclam® (Salamander Ltd, UK). The device functions as specified through a range of weather and site conditions.

In order to further identify the effect of sampling frequency on measured gas concentration, the monitoring period was alternated between 15 minutes and one hour at Site B (**see Figure 6** over). During higher frequency monitoring, the CH4 concentration is highly variable, changing by up to 10 per cent every 15 minutes. During hourly sampling, the concentration appears more stable, although this may not be an accurate reflection of the frequency of ground-gas migration events.

SHORT-TERM CONTINUOUS MONITORING: PUMP TESTS

Pump tests were conducted by purging the borehole with atmospheric air using an electric pump with a flow rate of $10\ l\ min^{-1}$ for 10 minutes. The air was directed down the borehole using a 5m pipe to promote displacement, this was sufficient to purge the CH4 concentration in all cases. After purging, the Gasclam® was inserted into the borehole making a gas-tight seal. Sampling was initiated immediately with a one-hour sampling frequency. All pump tests were conducted under stable atmospheric pressure. Multiple pump tests were carried out on each borehole to qualify the reproducibility of this method for characterising ground-gas recharge.

The gradient of the recovery profiles for borehole J are very similar, indicating that the experiments are reproducible for the same borehole under similar atmospheric conditions (**see Figure 7**). **cont..**

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The recovery profiles of borehole M and borehole J have very different gradients (**see Figure 8**). Considering the borehole geology and the spot-sampling data, a difference would be expected. Flow was regularly detected in borehole J and never in borehole M. Therefore, recovery at borehole J should be at a faster rate, and this is what is observed.

CONCLUSION

The continuous gas-monitoring programme at the two sites has demonstrated some potential flaws in the existing monitoring methodologies. Sampling frequency has been shown to influence measured gas concentrations. Furthermore, the identification of ground-gas regimes that vary on a site-specific basis highlights the potential for a mismatch between the frequency of sampling and the variability of gas concentration.

In some circumstances, a significant difference in concentration or variability in concentration can be measured between relatively small sampling frequencies. This highlights the importance of selecting an appropriate sampling frequency to avoid missing valuable information. It is apparent that to optimise the monitoring strategy, boreholes should undergo a degree of characterisation.

The difference between the concentration duration curves from the high-frequency continuous data and 'spot sample' measurements highlights the uncertainty of quantifying ground-gas concentration from spot sampling.

The ability to monitor environmental parameters and concentration simultaneously will provide an understanding of the processes controlling ground-gas production. Initial results suggest that the relationship between environmental parameters and concentration are complex and currently poorly understood. The potential for further understanding of processes will allow for a more representative conceptual model. This has a further impact on risk assessment, which is currently based on inferences of worst-case conditions determined by limited periodic measurements of gas concentration.

Initial results of using pump tests to characterise boreholes have confirmed the appropriateness of this technique for characterising ground-gas production using a borehole. Further work is required to model different recovery profiles to quantify gas production. The ability to quantify ground-gas production will have significant implications for the current UK risk-assessment framework. Therefore, the availability of affordable continuous monitoring equipment will result in a new approach to risk prediction.

FURTHER WORK

The IRP-IGM Project continues until November 2008 and will continue to:

- Use laboratory and computer modelling to quantify ground-gas flux from the recovery profile;
- Develop a working methodology for the Gasclam®;
- Determine the processes controlling ground-gas migration;
- Improve the current risk-assessment framework.

For more information on the IRP-IGM Project, please visit **www.gasclam.co.uk**

For more information on CL:AIRE and our Technology Demonstration and Research Projects please visit **www.claire.co.uk** email: **enquiries@claire.co.uk** or call: **+44(0)20 7258 5321**

FIGURES 2 - 8

Figure 2

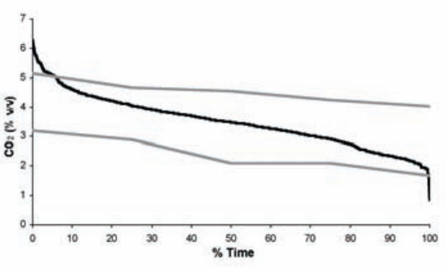
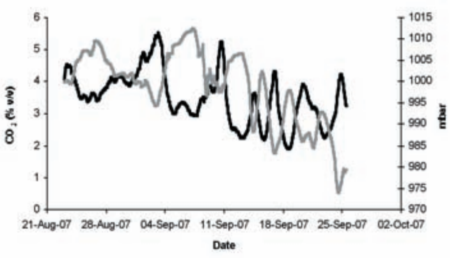


Figure 3



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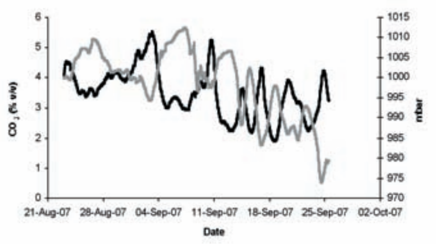

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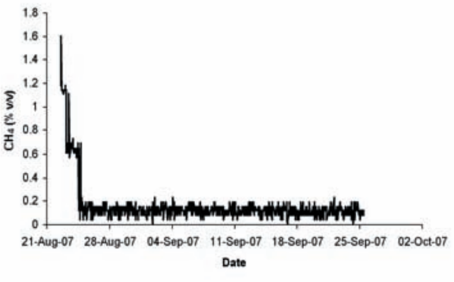

Figure 6

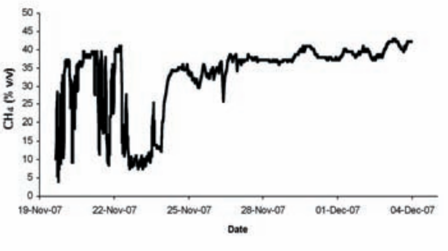

Figure 7

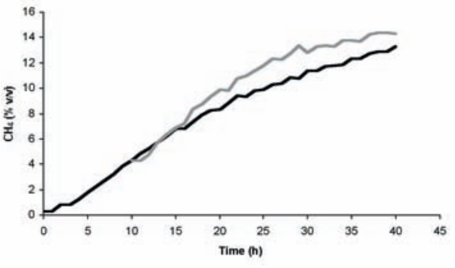

Figure 8

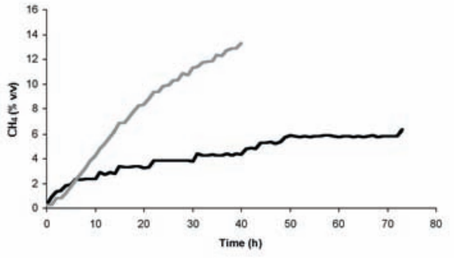

Figure 2: Flow duration curves of CO_2 at borehole M, Site A. The black line is constructed from the high frequency continuous data and grey lines compiled from random samples from the continuous data;

Figure 3: Continuous data from borehole C, Site A, CO_2 (black) atmospheric pressure (grey);

Figure 4: Continuous data from borehole J, Site A, atmospheric pressure (black), CH4 (grey);

Figure 5: Time series data from Site A;

Figure 6: Time series data from Site B. Data collected at 15-minute intervals between 19th-23rd Nov 2007 – the frequency was one hour for the remainder of the monitoring period;

Figure 7: Recovery profiles of borehole J, under stable atmospheric conditions;

Figure 8: Comparison of recovery profiles of borehole M (black) and borehole J (grey), under stable atmospheric conditions