Issues Involving The OSI Concept of Operation For Noble Gas Radionuclide Detection

C. R. Carrigan, Y. Sun

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Issues Involving The OSI Concept Of Operation

For Noble Gas Radionuclide Detection

Charles Carrigan and Yunwei Sun

Lawrence Livermore National Laboratory

Summary

The development of a technically sound protocol for detecting the subsurface release of noble gas radionuclides is critical to the successful operation of an on site inspection (OSI) under the CTBT and has broad ramifications for all aspects of the OSI regime including the setting of specifications for both sampling and analysis equipment used during an OSI. With NA-24 support, we are investigating a variety of issues and concerns that have significant bearing on policy development and technical guidance regarding the detection of noble gases and the creation of a technically justifiable OSI concept of operation. The work at LLNL focuses on optimizing the ability to capture radioactive noble gases subject to the constraints of possible OSI scenarios. This focus results from recognizing the difficulty of detecting gas releases in geologic environments - a lesson we learned previously from the LLNL Non-Proliferation Experiment (NPE). Evaluation of a number of important noble gas detection issues, potentially affecting OSI policy, has awaited the US re-engagement with the OSI technical community. Thus, there have been numerous issues to address during the past 18 months. Most of our evaluations of a sampling or transport issue necessarily involve computer simulations. This is partly due to the lack of OSI-relevant field data, such as that provided by the NPE, and partly a result of the ability of LLNL computer-based models to test a range of geologic and atmospheric scenarios far beyond what could ever be studied in the field making this approach very highly cost effective. We review some highlights of the transport and sampling issues we have investigated during the past year. We complete the discussion of these issues with a description of a preliminary design for subsurface sampling that is intended to be a practical solution to most if not all the challenges addressed here.

Introduction

Detection of noble-gas (NG) radionuclides such as Xenon-133 and Argon-37 significantly above background levels at a suspect site during an on-site inspection (OSI) is generally considered to be an extremely strong indicator of the recent occurrence of an underground nuclear explosion (UNE). Besides outlining a general approach to employing NG radionuclide detection capabilities during an OSI, this paper addresses several technical concerns and unknowns that will necessarily affect the concept of operation.

General OSI Scenario

To provide context for discussing issues pertinent to the OSI NG concept of operation, we assume that the International Monitoring System (IMS) has been triggered by seismicity and possibly wind blown atmospheric particulates and/or noble gases indicating a high likelihood that a UNE has occurred. Assuming permission to carry out the inspection is granted by the Executive Council (EC), we anticipate that an OSI will typically be initiated approximately 10 days or more following an event. By this time any cavity-pressure-induced seepage or venting of NG radionuclides may be minimal to nonexistent. While cavity pressure may be depleted within hours to a few days following a UNE, the heat released by the explosion can set up subsurface convective circulations driving detonation gases along the fracture network towards the surface. Such circulations have not been explored previously with application to transporting noble gases to the surface from an underground nuclear test. LLNL simulations for NA-24 involving cavity heat released into partially water-saturated, fractured environments suggest that thermally driven multiphase circulations may temporarily be more effective than barometric pumping in moving tell-tale gases towards the surface. Thus, thermally driven circulation involving vaporization of pore and fracture moisture will tend to enhance the potential for detecting NG at the surface by producing a more or less continual flow of detonation gases into a fracture-filled subsurface regime. Figure 1 illustrates how far from the cavity noble gases can be carried by multiphase (steam and

air) after only one day. This is a well-contained event and yet transport is effective at projecting a "halo" of gases around the detonation point out to more than 200m for both Xe-133 and Ar-37. This model assumes partial water saturation of the rock which is the most common situation that we expect to encounter as most UNEs are above the water table, putting them in the partially saturated regime. This model predicts that OSI-detectable levels of Ar-37 and Xe-133 could reach the surface after only one day although such levels would be too weak for detection by IMS NG monitoring systems. We will also attempt to evaluate transport to the surface where a detonation occurs below the water table. While it is historically less common to test below the water table for a variety of reasons, including the greater complexity of such a test, the possibility exists that an evader could perform such a test and therefore simulations of this type of event need to be undertaken.

We further assume that subsurface gas sampling is used primarily for the purpose of confirming an underground nuclear detonation, while atmospheric gas sampling may be used as a tool for both locating the site of a subsurface detonation as well as confirming that the detonation was nuclear in origin. While we do not exclude the possibility that subsurface sampling can contribute to reducing the search area, we recognize that the technique involves a labor-intensive effort that may not be appropriate for use in a broad-area search scheme, especially where manpower limitations exist and/or restrictions on time in the field are in effect, as was assumed in the Noble Gas 2009 Field Test (NG09). Subsurface gas sampling is not the preferred method of search area reduction and should only be considered as a means of search area reduction by evaluating only the most likely UNE sites in the inspection area if other better suited wide-area search methods (e.g., seismic after-shock monitoring, visual observations, surface gamma spectroscopy surveys, overflight, etc.) have failed to adequately locate the detonation site.

NG OSI Conops Issues

Visible Bedrock Fractures Versus Alluvium Covered Pathways

A network of fractures or other pathways, natural and/or UNE produced, with some vertical trending elements is a necessary condition for transporting gases to the surface from an underground detonation point. The Non-Proliferation Experiment (NPE) demonstrated that both visible and alluvium-covered fractures can produce detectable gases from an underground detonation. Three types of pathways were investigated in the NPE. Surficial cracks and fractures were observed and successfully used for subsurface sampling, which involved only small (0.01 L) samples where infiltration would not be a problem. Geologic surveys near the NPE surface ground zero (SGZ) also located gas-producing areas where non-visible fracturing was present in the subsurface (e.g., buried fault zone). Finally, random sample sites at SGZ, unconstrained by any surface or geologic observations, were found to have a very low potential for producing gas from the explosion.

Both visible and alluvium-covered pathways present challenges for successful sampling. Because of their direct connection to the atmosphere, visible fractures or cracks are most susceptible to allowing infiltration and sample contamination during the sample acquisition process while alluvium-covered pathways are more difficult or impossible to find. We discuss these issues in greater detail as well as possible solutions in what follows.

Detection Of NG Transport When Pathways Are Not Observable

Simulations performed by LLNL show that a 10m-thick alluvium layer blanketing the fracture regime still allows NG transport by barometric pumping along vertical trending fractures terminating at the base of the alluvium. If the mechanism driving gas transport is cavity pressure or thermal buoyancy, no limitation exists on alluvium thickness for detonation gases to be released into the base of the alluvium layer. The main concern

with the presence of alluvium is that it hides a producing fracture from visual observation. Furthermore, subsurface exploration methods such as ground penetrating radar or electromagnetic imaging as proposed for the continuation period of an OSI have insufficient spatial resolution to detect the existence of such fractures. Fortunately, NPE results show that the presence of producing subsurface fracture networks can still be inferred from observable geologic features such as fault scarps or grabens. Thus, when surficial fracturing is not visible, it is critical to understand, to the extent possible, the connectivity of the explosion-induced fracture regime and the natural fracture network associated with the local geology of the area.

Distributed Sample Point Pattern Vs. Single Sample Point

Besides using observable geology as an indicator of the presence of underlying fractures, we have also proposed a sampling-based solution for the case where producing fractures may lie beneath an alluvium layer. Instead of sampling from a single tube in the alluvium at a sampling station, we proposed emplacing multiple sample tubes distributed over the surface (e.g., 5-spot pattern as found on dice) and drawing uniformly subsurface gas from each tube. The scale of the pattern should approximately correspond to the anticipated average distance between fractures or rock joints. Of course, such scale information will not be directly known but statistical inferences may possibly be made from observations of locally visible outcroppings of bedrock or from places where fractured rock underlying alluvium has been made visible (e.g., a road cut, construction site, mine tunnel or quarry). At LLNL, we have performed simulations of sampling with spatially distributed sampling tubes around an unknown fracture and find this approach to be superior to sampling only using one tube when the position of the underlying fracture is unknown. Another advantage of drawing gas samples from multiple tubes rather than one tube is that smaller volumes will be required from each tube, thus minimizing the possibility that infiltration of atmospheric gases will occur. In addition, a large-volume gas sample can be acquired more quickly from five sample tubes than from only one tube as subsurface sampling tends to be flow-rate limited.

(Installation of five sampling tubes instead of one at each site is clearly more time consuming and represents a trade-off that must be considered.)

Using Radon & Other Radionuclides To Detect Producing Subsurface Fractures

Subsurface NG producing fractures may also be potentially located by detecting other natural and detonation-produced radioactive gases that emanate from them. Naturally occurring radon has been used by geophysicists to detect faults and fractures in the subsurface by traversing a zone and sampling periodically near the surface for peaks in the radon concentration. Discussions with equipment vendors (Radon 2010, Prague) and with Dr. Ales Fronka (SURO, CZ) suggest that existing radon samplers can be tuned for operation to allow for rapid near-surface probe sampling to locate zones of higher radon concentration. In an area where a suspected UNE has occurred, detonation produced radionuclide gases may also be deposited at shallow depths above fractures. Thus, the detection of any significant peaks in subsurface radioactivity of any type may imply that a producing fracture network is nearby. Quick subsurface gas sampling with a probe using a walking survey approach (i.e., probing the subsurface at points following a laid-out grid) to locate hidden producing fractures is currently being considered at LLNL.

Large Volume Sampling

The detection of tracer gases in the LLNL NPE required subsurface sample volumes of only 0.01 liter for analysis. The requirement for Xe-133 (SAUNA) and Ar-37 (MARDS) analyses is currently one to two thousand liters. This large volume requirement creates new sampling issues that did not exist during the NPE sampling process. The issues arise primarily from infiltration of atmospheric gas into the subsurface during the sample extraction process. At the least, mixing of atmospheric gas into a soil gas sample results in dilution of the sample and loss of Xe-133 detection sensitivity. At worst, atmospheric gas containing Xe-133 released from a nearby legitimate Xe-133 source (e.g., a medical isotope production facility) can result in a false positive detection. Thus, it is important from an OSI protocol development perspective to both understand the problem as well

as possible approaches to minimizing its impact on interpreting the results of Xe-133 analyses during an OSI.

With NA-24 support, LLNL performed large-volume sampling experiments as part of the CTBTO NG09 Field Test in Slovakia. The analysis of the samples obtained from the experiments and interpretations with numerical simulations using the LLNL NUFT program were completed in 2010 (Carrigan and Sun, INGE2010 Presentation, 2010).

The basic large-volume sampling station setup used in the experiment is broadly similar to that presented as a recommendation of this white paper and is illustrated in Figure 2. A station was constructed by auguring a 5cm (2in) diameter hole about 1.5m deep in alluvium. A sampling tube mounted within an inflatable rubber packer was inserted into the hole above any water residing in the hole. The packer was inflated against the hole wall to eliminate air leakage along the hole. A 3m x 3m plastic sheet tent was placed over the sample tube and sealed around the tube to prevent air leakage. The edges of the tent were buried in the soil to prevent leakage under the tent. The sample tube was connected to a small pump which was in turn connected to a plastic sample bag. Turning on the electric pump would draw gas from the hole, transferring it to the sample bag. A small sample port on the outlet side of the pump allowed us to take periodic syringe samples for later analysis.

Prior to turning on the pump and starting the gas-sample extraction, charges of sulfur hexafluoride (SF_6) tracer gas were released under the tent. As gas is extracted from the buried end of the sample tube, pore gas will be drawn both from above or below the sample point to replace the gas that is removed. Because only soil gas is desired in the sample, significant flows from above that eventually draw in atmospheric gas are to be avoided. Very small samples, as required by the NPE, did not result in significant atmospheric gas being drawn down into the sample tube. On the other hand, the massive volumes of gas required during an OSI (as driven by the Xe and Ar analyses

requirements) risk the possibility that atmospheric gas will be eventually drawn down into the buried sample tube unless it is emplaced very deeply. Unfortunately, sufficiently deep emplacement for the volumes of gas involved may not be possible owing to inadequate alluvial layer thickness or the sensitivity of the Inspected State Party (ISP) to the perceived degree of invasiveness. In the experiment, the presence of SF_6 detected in a gas sample indicates that gas from the atmosphere has indeed been captured. If the concentration of SF_6 under the tent is known initially, then an estimate of the amount of atmospheric gas in the sample can be made.

One means of reducing the impact of infiltration is to use a tarp or plastic sheeting to cover as much surface area around the sample point as is practical. Simulations (Figure 3) show the effect of using a 3m x 3m tarp in a sampling arrangement similar to that used in NG09. As shown in the figure, use of the tarp allows more gas to be drawn from the subsurface than from the atmosphere which is desirable. The contribution of atmospheric gas decreases with increasing tarp size in this model. A large enough tarp can prevent any infiltration. What is "large enough" depends on the properties of the alluvial layer in which the sampling is performed, sample tube depth and the volume of the sample required.

Large-volume sampling was performed at two different sites during the NG09 field test. The sampling set up is described as above and used SF_6 to monitor any infiltration. One of the sites was located in an old rock quarry on the Slovakian military base used for the field test. The quarry bottom was covered with a thin alluvial layer apparently overlying highly fractured bedrock, as indicated by the surrounding quarry walls which were themselves highly fractured. The sampling hole was augured using a water spray to cool the auger. At "Quarry" it was found that water drained from the hole unexpectedly quickly, thus indicating that the soil and rock below the sample point was highly permeable. The sampling pump extracted soil gas at a rate of approximately 6 liters/min filling the sampling bag over a period of several hours. During that period, small samples

of gas flowing through the pump were periodically withdrawn from the sample port while noting the cumulative volume that had been withdrawn at the time of sampling. The syringe samples were capped and later analyzed. The SF_6 concentraton detected as a function of the total gas withdrawn from the well is shown in Figure 4. For most of the 1.8 m^3 withdrawn, the tracer was measured at about background level. (One spurious data point above background is apparently due to contamination of the sample.) Only after the sampling site had been left overnight and the packer pressure had dropped, giving rise to leakage from the surface past the packer, was a large SF_6 signal observed the next morning. The quarry hydrologic example represents a highly desirable sampling environment with a thin protective alluvial cover overlying a highly fractured bedrock regime. The fact that the extraction process introduced tracer gas into the sample provides a lesson in the need to always keep the packer well sealed against the wall of the hole. Because the hole wall is somewhat plastic and moves in its response to the inflating packer, it may be necessary to continually increase the packer pressure. As this may be impractical over a long period of time (days to weeks), use of a wet bentonite clay for filling the sampling hole above the packer is recommended.

Another sampling site called "Turkish Hill" exhibited opposite, highly undesirable sampling behavior. The hill was selected because of the underlying stratigraphy and surface grading. However, unlike the quarry site with a thin alluvial layer overlying fractured bedrock, the hill site consisted of multiple alluvial layers overlying each other. It was found that residual water was slow to drain from the hole and the soil was largely saturated, causing a significant decrease in gas permeability. As the tracer concentration illustrates in Figure 5, atmospheric gas leaked almost immediately into the sample tube. According to the observed tracer concentration, about 30% of the sample was composed of atmospheric gas. Because the gas permeability was so low owing to the water saturation level of the soil, the electric pump drew down the sample point pressure until the seal between the packer and soil was probably compromised, resulting in a constant leakage of atmospheric gas past the packer into the sample tube.

This type of site should be avoided if possible since it is unlikely to produce a satisfactory sample. We also learned that a pressure transducer at the sample point might be helpful to monitor for excessive pressure decreases that might cause leakage past the packer-hole seal.

Argon-37 Background in Soil

With NA-24 support we are also looking at the existence of natural and man-made background levels of isotopes that represent a lower limit or barrier for the detectability of UNE-generated isotopes. For UNE confirmation purposes, Ar-37 is highly attractive as a short-lived noble gas isotope because it is very rare and significant amounts of it appearing above any local background level are indicative of a recent subsurface nuclear event. While natural background levels are extremely low, coincidence counting methods are so sensitive that even these exceedingly low background levels may be detectable in practice. The OSI noble gas concept of operation should take into account, to the extent possible, the existence of such background levels of isotopes of interest with the objective of optimizing the detectability of actual UNE-produced Ar-37 signals. Some knowledge of background levels is always required before the existence of an anomaly or significant deviation from the background can be shown to exist.

Recent work by Robin Riedmann of the University of Bern, Switzerland as part of his PhD research involves measurements of the Ar-37 background in shallow soils. Figure 6 illustrates the vertical profile calculated and measured for concentrations (mBq/m^3 of extracted soil gas) of this isotope at one location in Switzerland. The theoretical calculation considers cosmic-ray neutron bombardment of the soil and collisions with native Ca-40 to produce Ar-37. The peak production in this example occurs between 1 – 2 m depth. Given the apparent agreement between the theory and observations, assumptions made in Riedmann's calculations are evidently well met at the sometimes snow-covered sampling site where vertical profile measurements of Ar-37 have been

obtained. Both his calculations and field data show peak values of about 130 mBq/m^3 occurring in the soil.

To better understand the applicability of Riedmann's model for the Ar-37 depth profile, which ignores soil gas migration effects, we have simulated models of soil gas migration in the upper few meters of the soil caused by daily fluctuations in the barometric pressure. We use actual pressure records to simulate the pressure changes occurring at the soil surface. We also use soil properties and a soil-bedrock stratigraphy characteristic on average of what might be encountered at an OSI site or, at least, what might be appropriate for detecting a UNE-produced noble gas signal at an OSI site. To see how effective the soil gas exchange occurs between the atmosphere and underlying fractured bedrock, our model assumes an initial condition of uniform tracer gas concentration throughout the thickness of the soil layer. As time progresses after the start of the simulation, the constantly changing pressure at the ground surface produces both an upward migration of soil gas from shallow depths in alluvium (e.g. 1-10m) to the surface as well as a downward migration of the soil gas into the underlying rock fracture system. Figure 7 shows how the initially uniform concentration of a tracer gas in the top 10 m of the soil changes over a period of 35 days. Interestingly, we find that the depth zone (1-2m) that would normally correspond to the Ar-37 peak in Riedmann's model is also the most effectively swept zone by gases migrating to the surface. If this barometrically induced flow is included in Riedmann's model it is likely that no peak in Ar-37 concentration would exist at all. This does not mean that Riedmann's model is wrong, but it does suggest that further evaluation of his model is warranted to better understand its relevance to OSI.

Finally, near-surface gas exchange between the atmosphere and soil caused by barometric pumping as modeled in Figure 7 can also introduce contaminant gases from the atmosphere, such as Xe-133, creating the low probability of a false positive. We have performed simulations showing that atmospheric gas containing Xe-133 could be

mixed with soil gas under certain circumstances. Likely sources of atmospheric Xe-133 contamination are typically from medical isotope production laboratories (Hebel, 2010; Friese, 2011). Concentration levels of 100 Bq/m^3 have been detected 10-20km downwind from such facilities (Ted Bowyer, personal communication, 2011) and could produce detectable backgrounds in the soil under certain circumstances according to our model. Because these result have implications for how background levels of both Ar-37 and Xe-133 should be determined, further evaluation of barometrically induced near-surface soil gas flow is recommended.

The message that can be taken from studies of noble gas backgrounds and the effect of barometric fluctuations on near-surface soil gas migration is that deeper sampling is better as we are more likely to obtain samples from deep sources of noble gases, such as UNEs, that are uncontaminated by near-surface or atmospheric sources of these gases as we have already shown. Again, the limit on how deep we can emplace sample sites depends on the depth of any overlying alluvial layer, the available equipment for auguring holes in the context of OSI limitations and the perception by the ISP of the invasiveness of the sampling procedure.

Barometric Triggering Of Sampling Vs. Rapid Bulk Extraction

Another issue is the value of performing barometrically triggered gas extraction during the acquisition of a sample. Both NPE field experiments, simulations, and previous work (Nilson, 1991) have shown that shallow detection of gases emanating from a deep source is tied to extracting gas samples at a site during a falling barometer and before reaching the minimum of a barometric low. In the case of the NPE, this was usually accomplished by obtaining field samples before the arrival of a storm on Rainer Mesa at NTS. This conclusion assumes that the samples are small as obtained in the NPE experiment. When the sample volumes are thousands of times larger, as required for Xe-133 and Ar-37 analyses, acquiring a sample during a single barometric low of an hour or two may not be possible; sample acquisition in such cases may be over the time

periods of several barometric lows during possibly one or two days. Preliminary evaluation at LLNL shows that taking bulk samples at one time can be effective if the sampling point is deeper in the soil. How optimal large ($\sim$1m^3) samples are obtained during an OSI is of critical importance and we are continuing to investigate this issue.

Surface Tracer Gas Sampling For Quality Control

As already discussed, we performed a series of experiments during NG09 addressing the infiltration of shallow gas sampling stations when large volume samples are required. We used a "tent" arrangement to contain sulfur hexaflouride (SF_6) gas above the surface over the sampling point (see Figure 2). When atmospheric gas, that is, gas from the surface, was drawn into a buried sampling point, SF_6 would be entrained in the flow from the surface. Estimates of the amount of infiltrated gas from the surface can therefore be obtained by measuring the amount of SF_6 in a sample. For example, the amount of entrained surface gas entrained in the soil gas extracted at the "Turkish Hill" site (Figure 5) was about 30%, which would have undoubtedly led to rejection of the sample for OSI purposes.

Using SF_6 tracer gas, this basic approach can be applied to monitoring extraction quality control during acquisition of a large volume gas sample. The ISP may then be assured that a sample has not been contaminated by gas from the surface that might contain a noble gas from another source unrelated to the suspect site. Even if some tracer is detected, we can use the tracer concentration to estimate the level of contamination of the sample and demonstrate, if required, that the level of possible atmospheric contamination is negligible. We are continuing to look at this in the context of developing an optimal large volume sampling approach capable of addressing the technology and policy requirements of the OSI regime.

Conops Approach To Subsurface Sampling

Taking into account the concerns and issues already mentioned (e.g., hidden producing fractures, infiltration, flow-rate limiting of sample acquisition, etc.) we propose a preliminary, generalized model of subsurface noble gas sampling. Sample tubes for a given station are emplaced in a 5-spot pattern (Figure 8) at the greatest depth that is reasonably attainable given field conditions, manpower and equipment availability and any Inspected State Party concerns about degree of invasion. The tubes are installed in augured holes using inflatable packers. To further guard against infiltration, gas-tight plugs are formed above each packer by filling the remaining hole to the surface with a water-saturated, radionuclide-free bentonite clay mixture. The 5-spot pattern is then very broadly tarped with plastic sheeting (note: the horizontal dimension of the sheeting should preferably be many times the vertical depth of sampling). If it is deemed necessary, SF_6 infiltration monitoring gas may be injected under the tarp. Each of the sampling tubes is connected by rigid vacuum tubing to individual, rate-controllable electric pumps. All equipment used in the sampling station is constructed of materials having no memory to noble gases or any tracer gases (e.g., SF_6) used for monitoring atmospheric infiltration.

More sophisticated realizations of this design may include computerized control of the electric pumps allowing decreases in local barometric pressure to trigger the sampling of the site. The results of the NPE and other experiments along with computer simulations at LLNL indicate that especially for shallow sampling (~ 1-2 meters) barometric triggering of soil gas extraction may produce a greater likelihood of detection. In addition, monitoring pressure changes at the buried end of the sample tube will permit pumps to be turned off before seals are broken and infiltration occurs as a result of leakage past a packer.

Each of the electric pumps draws gas from its respective sample tube releasing the gas into a common low-pressure tank or container (e.g., high quality, puncture resistant

inflatable bags) that remains at the site. The contents of this low-pressure container can be periodically transferred via a portable compressor to a pressure-rated tank which is then transported to the base of operations for analysis.

Conclusion

In the process of developing a sound concept of operation for noble gas sampling, it is necessary to confront a variety of technical issues. Some of these issues are sufficiently specific to the OSI regime that they have not been well studied by other researchers. In this short paper we have described highlights of the issues and concerns that we have either addressed or are currently being considered with NA-24 support. We have also suggested solutions to some issues (e.g., large volume sampling approach and sample quality control monitoring) based on field and modeling results that are intended to optimize the probability of UNE-produced noble gas detection. We believe that we are now in a position to begin formulating a noble gas concept of operation while recognizing that it will be a dynamic product that should benefit from continued research and improvements in understanding of the subsurface regime. While computer simulations are helpful during this formulation process, we recognize that field experiments and trials of the resulting concept of operation are crucial for its successful development and recommend planning a series of table-top and field evaluations prior to any integrated effort such as IFE14.

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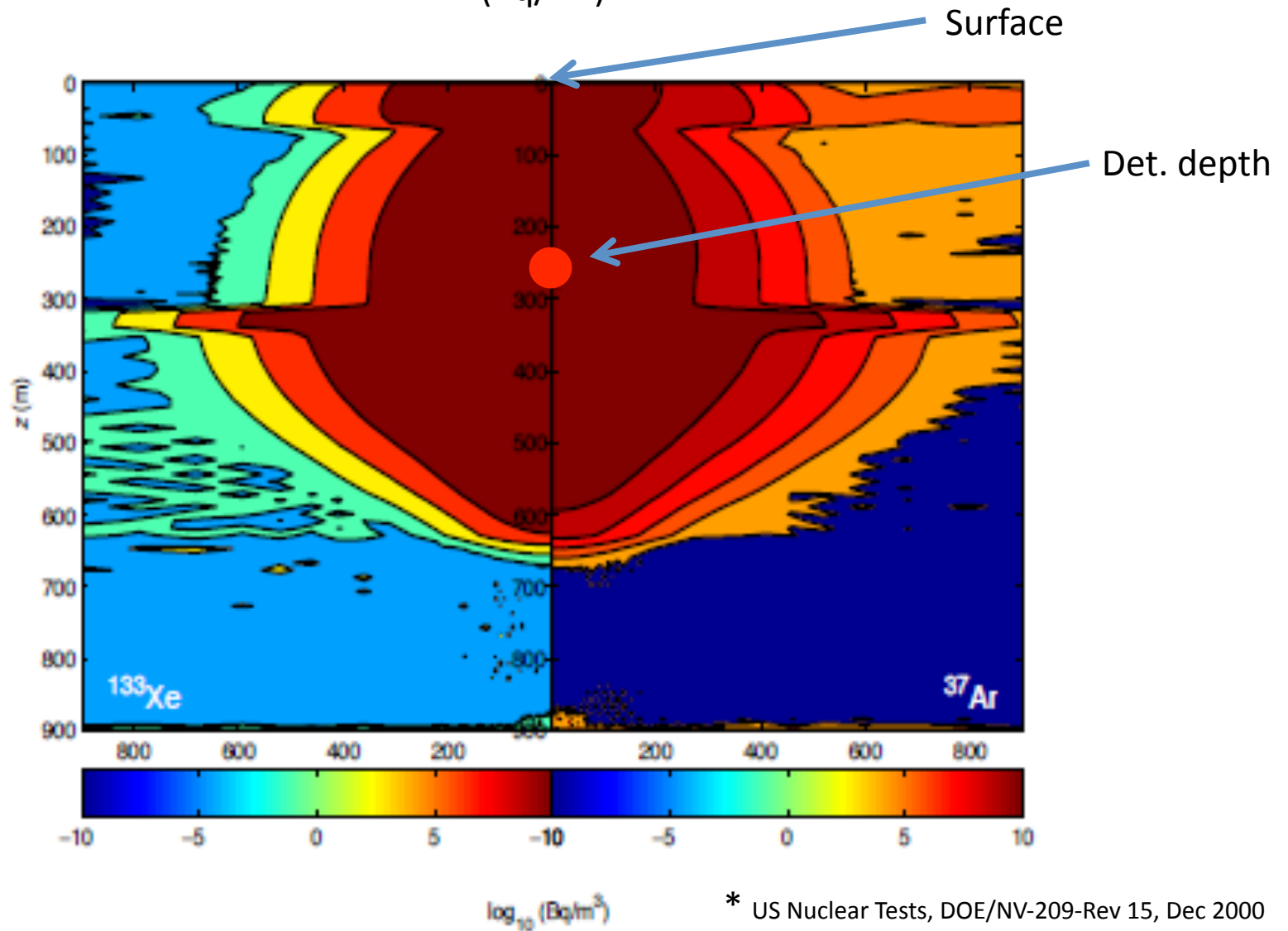
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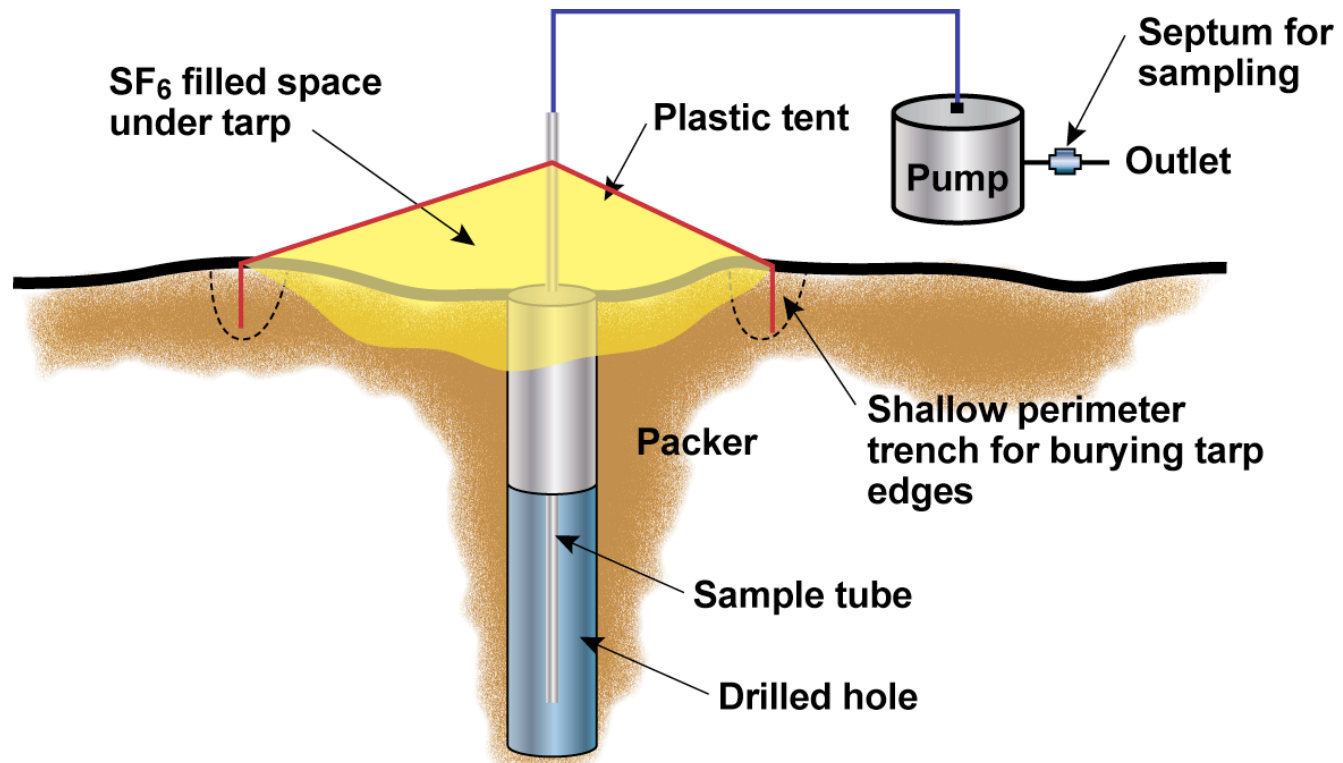
Figures

Simulated Rainier Test (1.7 Kt*) gas contours
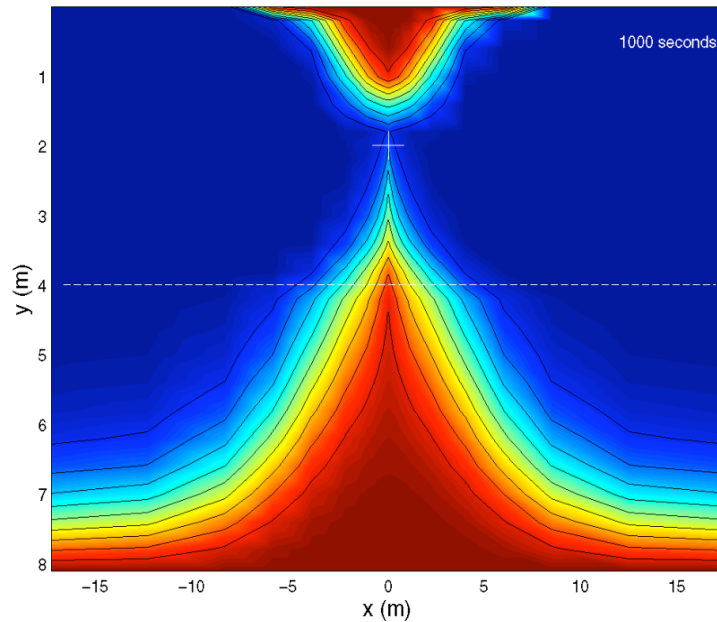at 1 day for Xe and Ar
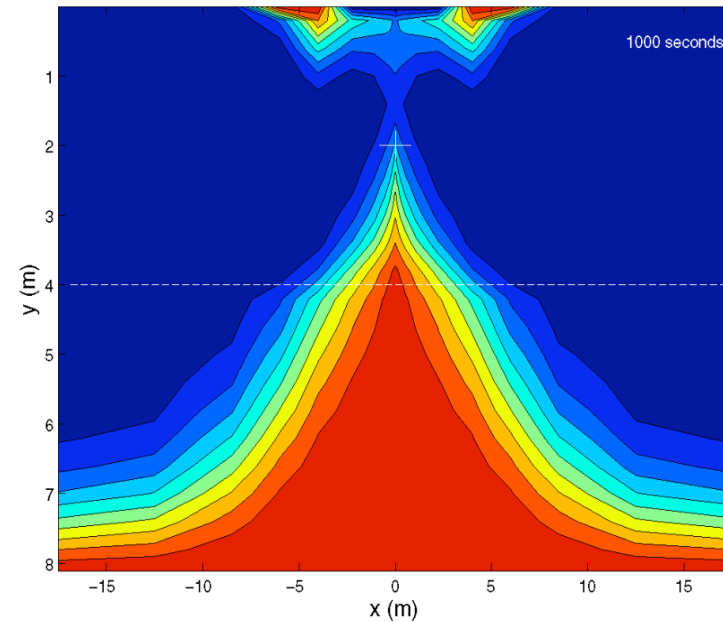(Bq/m³)

* US Nuclear Tests, DOE/NV-209-Rev 15, Dec 2000

Figure 1

Sample station arrangement for NG09 experiments

Figure 2

# Effect of plastic ground cover in quarry experiment

Contour of tracer concentration without using tarp. (Sample 153)

Contour of tracer concentration using tarp. The diameter of tarp needed for preventing air infiltration from atmosphere is a function of pumping rate and depth.

Figure 3

NG09 quarry sampling example

High Permeability Fractured Medium

Quarry (17a)
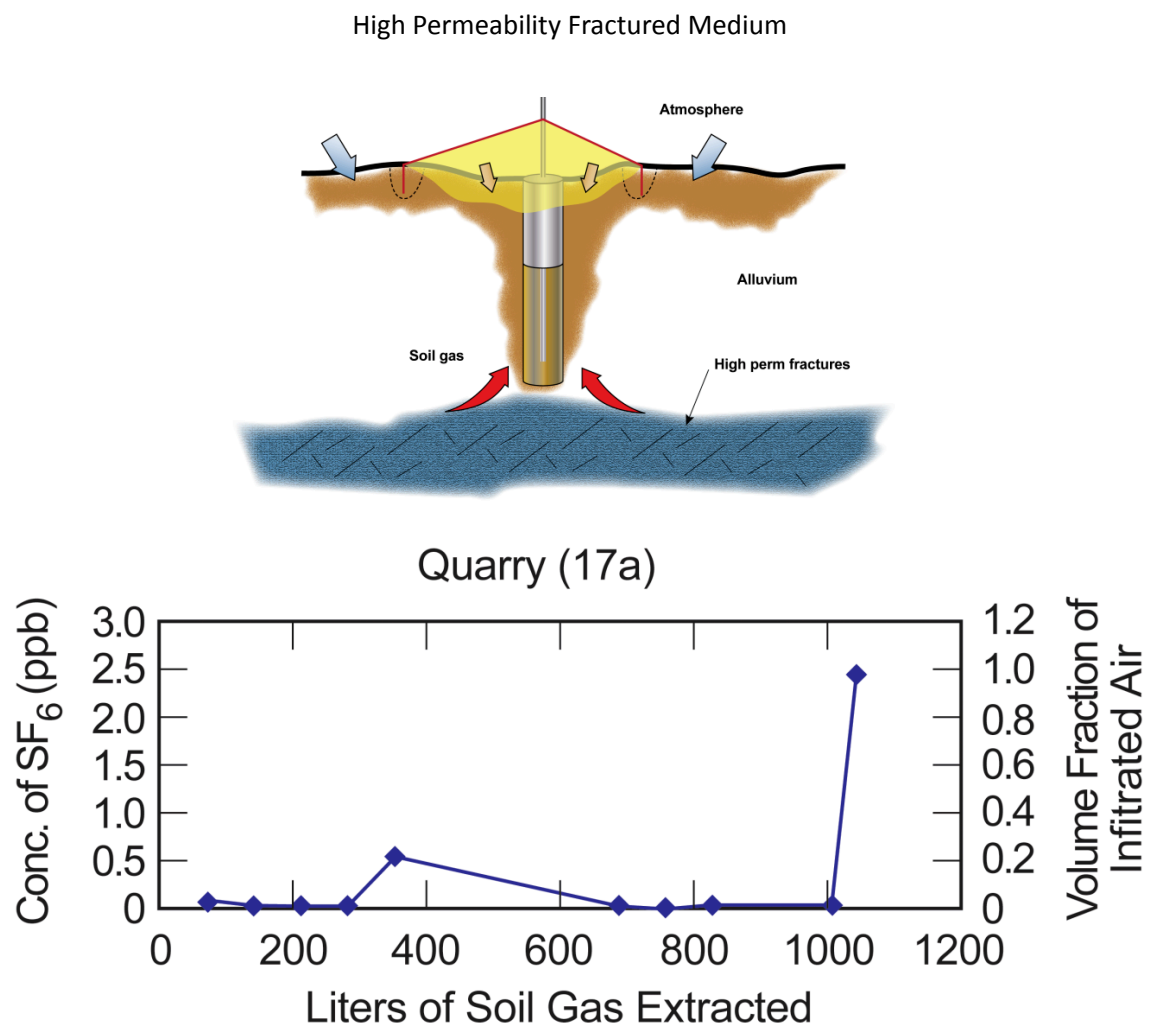
Figure 4

NG09 "Turkish Hill" sampling example
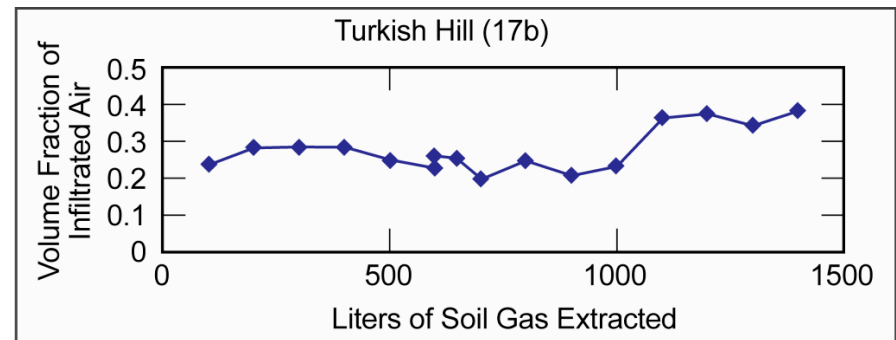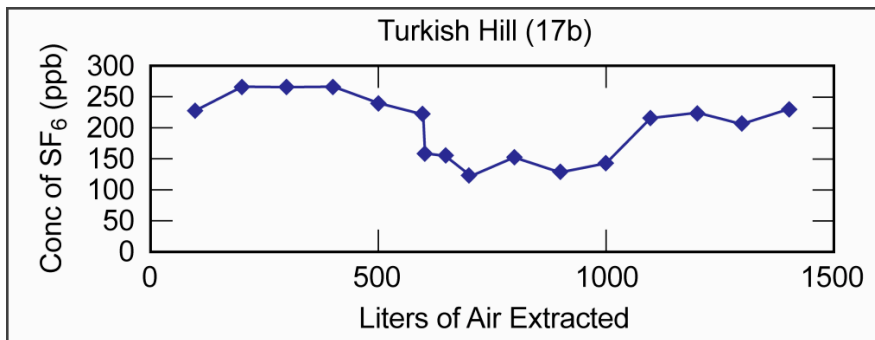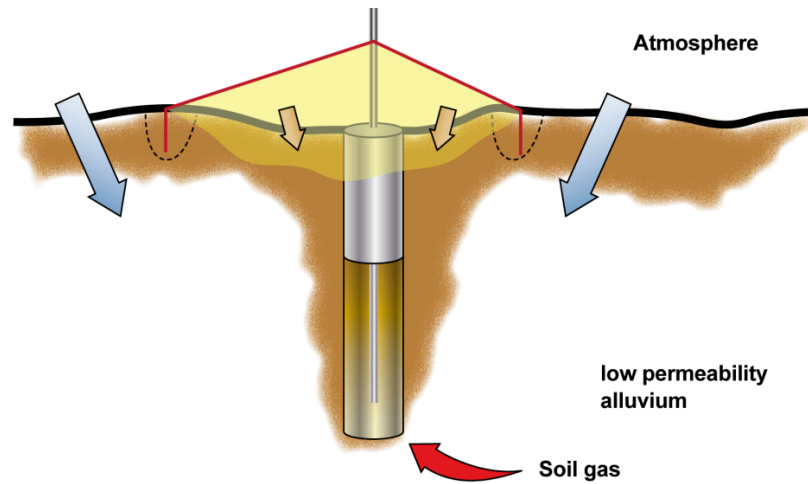

Figure 5

Riedmann Model For Vertical Profile Of Ar-37 Background In Soil

Peak value of Ar-37 may be significantly reduced or vanish due to gas exchange between soil and atmosphere as shown in Fig. 7
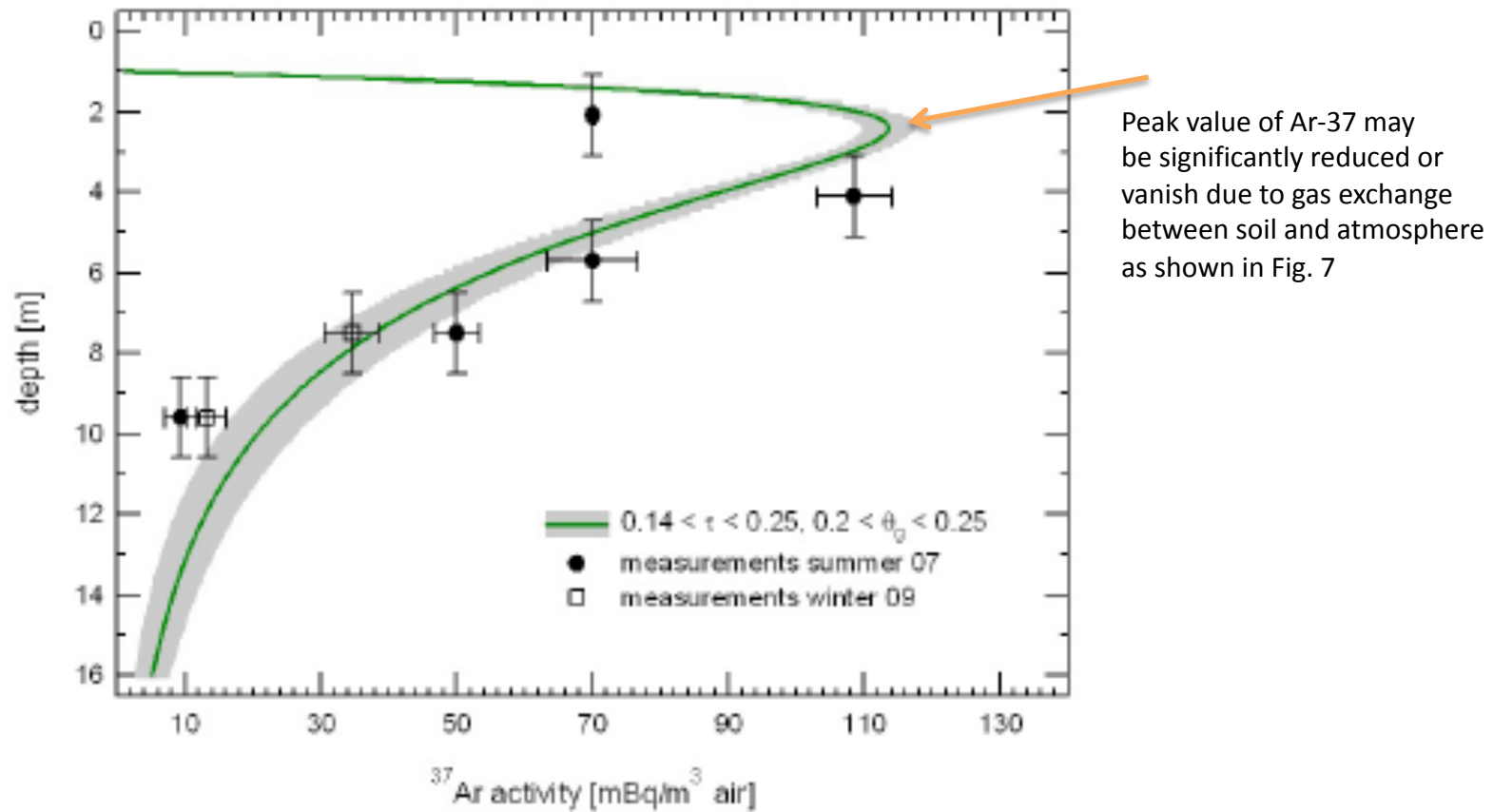
Based on known assumptions in Riedmann's model for the vertical profile of the Ar-37 background, it appears that is applicable to soils where gas exchange between the atmosphere and soil can be neglected. This may apply in regions where permeability is low because of freezing or high water content. However, soil gas exchange will be much more vigorous at sites readily susceptible to subsurface noble gas sampling (Fig. 7).

Figure 6

Simulations of soil gas/atmospheric gas exchange in soil
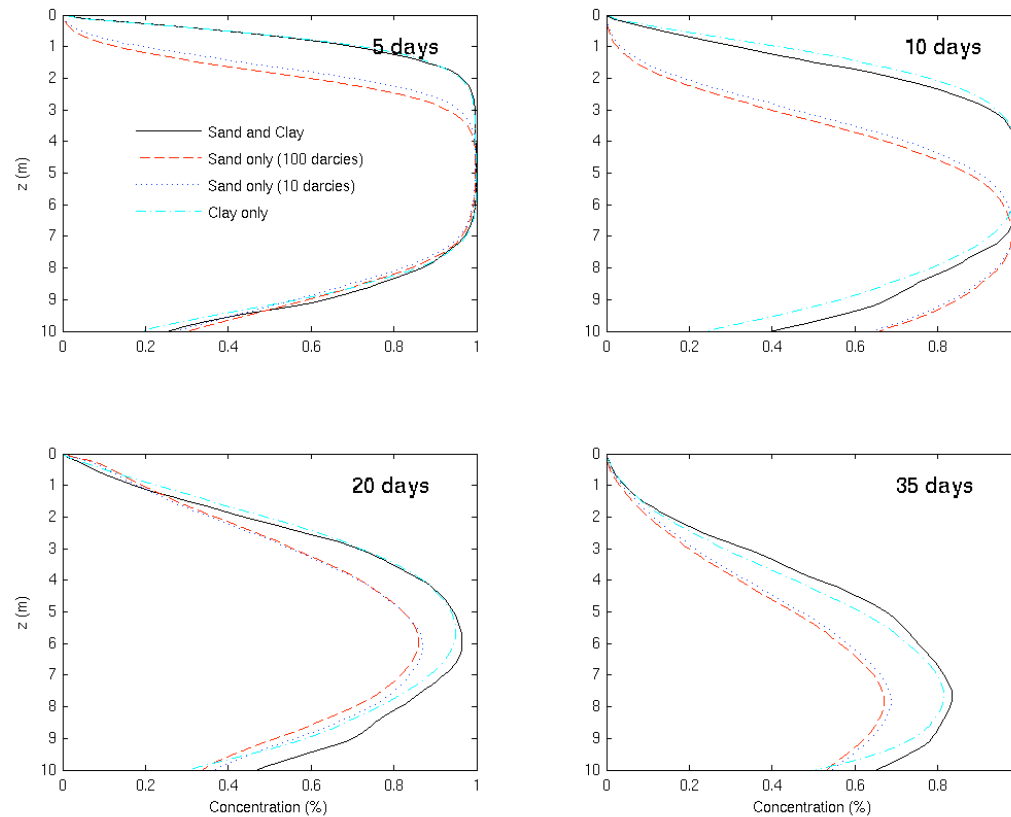
LLNL simulations of the change in concentration of a tracer from 5 to 35 days. Plots show vertical profile of concentration. Importantly, barometric pumping strongly reduces concentration at 1-2 m depth corresponding to the same zone that contains the Ar-37 peak concentration in Riedmann's model. Result suggests that for OSI sampling regimes of interest, the peak Ar-37 background will be somewhat smaller than predicted in Riedmann's calculation.

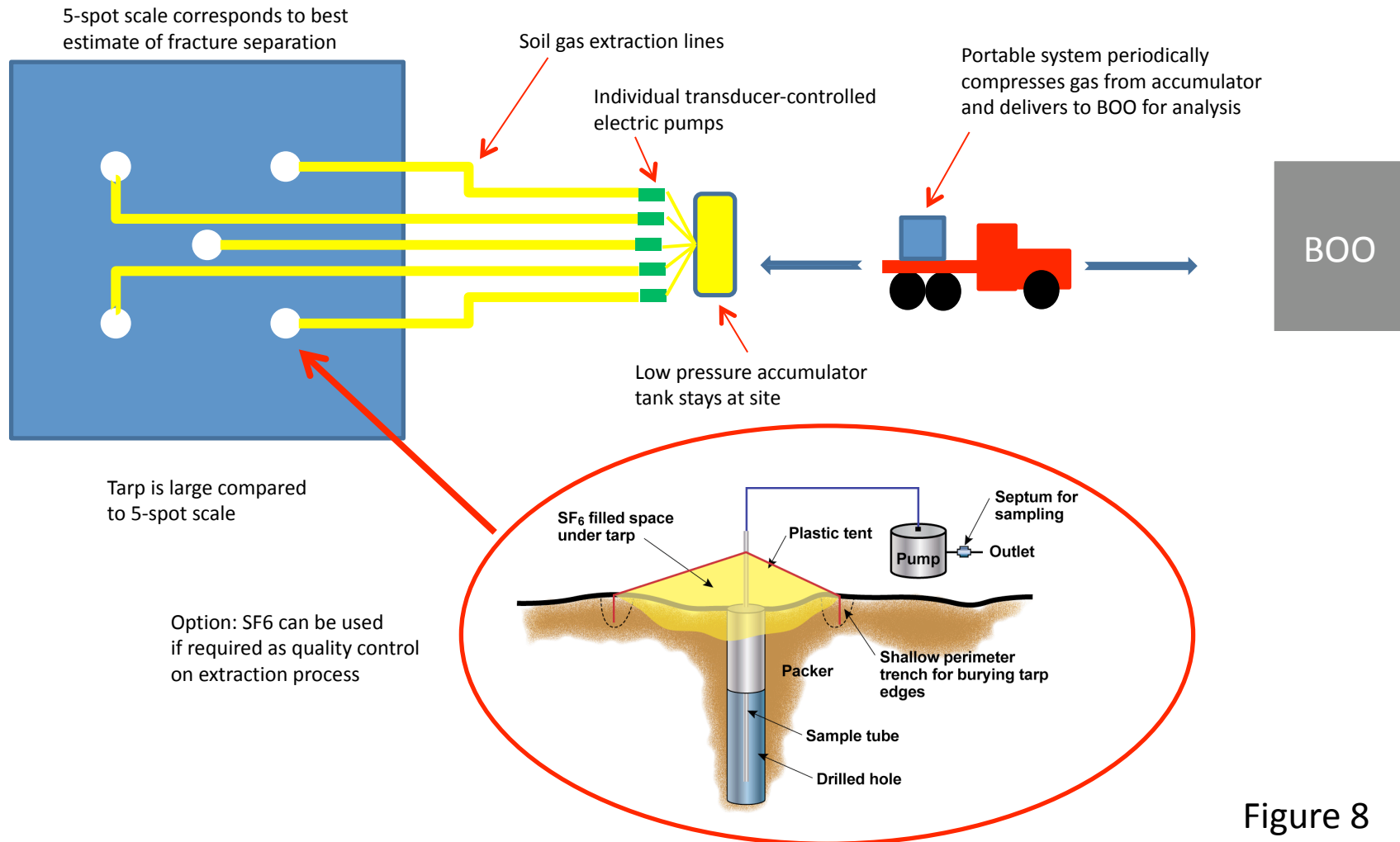Figure 7

Proposed 5-Spot Soil Gas Extraction System

5-spot scale corresponds to best estimate of fracture separation

Soil gas extraction lines

Individual transducer-controlled electric pumps

Portable system periodically compresses gas from accumulator and delivers to BOO for analysis

BOO

Low pressure accumulator tank stays at site

Tarp is large compared to 5-spot scale

Option: SF6 can be used if required as quality control on extraction process

SF₆ filled space under tarp

Plastic tent

Septum for sampling

Pump

Outlet

Packer

Shallow perimeter trench for burying tarp edges

Sample tube

Drilled hole

Figure 8