

Selected Technical Papers



STP 1570

Continuous Soil Gas Measurements: Worst Case Risk Parameters

Editors:

Lorne G. Everett
Mark L. Kram



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Foreword

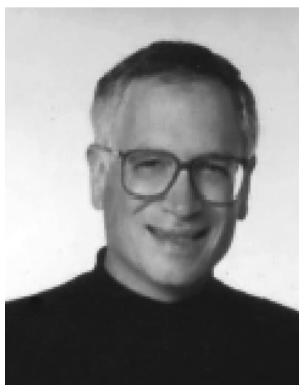
THIS COMPILATION OF *Selected Technical Papers*, STP1570, *Continuous Soil Gas Measurements: Worst Case Risk Parameters*, contains peer-reviewed papers that were presented at a symposium held January 30, 2013 in Jacksonville, FL, USA. The symposium was sponsored by ASTM International Committee D18 on Soil and Rock and Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

The symposium Chairman was Lorne G. Everett, L. Everett & Associates, LLC, Santa Barbara, CA, USA. The symposium Co-Chairman was Mark L. Kram, Groundswell Technologies, Inc., Santa Barbara, CA, USA. They both served as Editors of the STP.

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Dedication



Martin N. Sara, of Environmental Resources in Rolling Meadows, IL, died July 10, 2006. (Reproduced in part with approval from ASTM Standardization News) He had been an ASTM International member since 1987 and worked on many subcommittees in Committee D18 on Soil and Rock. A founding member of the D18 groundwater activity and a member of the board of directors for the ASTM Institute for Standards Research, Sara had also been a member of Committee E50 on Environmental Assessment, Risk Management and Corrective Action and the ASTM standing Committee on Publications. For his service to D18, Sara had received the A. Ivan Johnson Outstanding Achievement Award in 2001, a Special Service Award in 2003, and the Woodland G. Scheckley Memorial Award.

I spent many days and evenings with Marty working on ASTM standards to make them relevant to field and regulatory practitioners and to get some consistency in hydrogeologic testing and interpretation. Marty also provided substantial funding for me to conduct field demonstrations at Kettleman Hills, California and to conduct site evaluations at the Chemical Waste Management Facility at Arlington, Oregon. Marty was an inspirational kind of guy that everybody wanted to be around. He loved life! It would be remiss of me not to dedicate this book to Marty for his friendship, contributions to ASTM and to the theme of this book which focuses on soil gas behavior and vapor intrusion, a theme Marty was concerned with at every Waste Management landfill facility.

Martin ("Marty") N. Sara was one of the truly outstanding practicing American hydrogeologists of his time. (Reproduced in part with approval from Dr. Allen Hatheway) Marty, who was born of Dutch-American roots, in Chicago, Illinois, graduated (1969) in geology from the University of Illinois. He then struck out to the West, joining Jim Warner, P.E., the legendary construction water control grouting specialist. In this job, Marty worked for a perfectionist

but withstood the attendant pressure and was quickly placed in charge of his own projects.

Marty's willingness to seek difficult and challenging assignments forged his basic character as a technically fearless practitioner. Marty learned early to focus not only on the imperatives of his career, but also on working cooperatively to make the profession a better place to practice, as well as to serve the public. Marty's dedication to the practice of engineering geology and its important sub-element of hydrogeology defines a true "calling" to the profession. He held geological licensure in California, Florida, Indiana, Oregon, Pennsylvania, and Wisconsin.

Marty started out as an engineering geologist, but his involvement always seemed to be in intimate contact with the considerations of groundwater. In this way, and by circumstance, he migrated into the combined area of practice in hydrogeology as applied to site characterization for waste management facilities in the 15th year of his practice (1985).

For the next 21 years, Martin Sara was a constant and always rising presence in and around the practice of hydrogeology. Though he might not have been considered one of the groundwater movers and shakers by academic and government "insiders" to the profession, this indeed was his ongoing impact, and now, his legacy.

Marty in 1971, was with the late Dames & Moore (D&M; geotechnical consultants then headquartered in Los Angeles) and was "on his way up" in that organization. D&M had pioneered several major innovative practices in what was then known as "soils engineering," which Marty was adept at by that point in his developing career:

- Project geologists performed all data gathering field activities, supervised lab testing, and worked closely with the soils engineer in developing design recommendations;
- Great attention was given to field sampling techniques, mainly designed to provide minimally disturbed samples for one-inch (thick) brass ring slices taken from the "California" drive sampler;
- Active participation in report writing, and;
- Close attention to client relations.

Responding to the well-known draw-to-return that affects Midwesterners, Marty transferred to the Chicago office of D&M in 1975, but was a first-responder to take the company's interests to the Republic of South Africa, in Johannesburg, where he remained for a decade and spent most of that time as manager of the venture. The portrait here is Marty's passport photograph taken in his 28th year, as he and his family departed for South Africa.

In late 1984, Marty returned to Chicago and experienced the turmoil of the drawdown of the established North American consulting firms, the gravity of

which eventually destroyed the nature of the profession that many of us had grown up in. These were the well-known forces:

- The crash of the nuclear power plant siting (PSAR; Preliminary Safety Analysis Report) work;
- Federal attacks (U.S. Department of Justice) on qualifications-based selection of professional services;
- Federally fostered bid-shopping and commoditization of professional engineering (and applied geologic services), and;
- The special-interest set-asides for award of professional services on federal funding projects.

Due to declining revenues and incoming work resulting from funding allocations to various forms of minority and disadvantaged participation in the applied geosciences, as well as being on the low-end of owner-contact in project management, the geotechnical profession was reeling. About that time, the welcome alternative was project work in the new “geoenvironmental” field, which was on the rise in waste management and cleanup work.

With Marty’s support, “Waste” (as WMI was then known in our profession) was employing literally dozens of consulting geological and engineering firms. “Waste” had no safeguard against substandard submittals from its consultants. The main problems stemmed from a lack of corporate standardization of qualifications for selection, scope of work, and report format and content of siting, permit application and environmental response reports. These reports were reviewed internally and then submitted by “Waste” to the U.S. Environmental Protection Agency (established only in 1970) and to the ensuing State environmental agencies being established under RCRA (Federal *Resource Conservation & Recovery Act* of 1976).

Before Peter Vardy sold his ownership interests in WMI and departed, in the late 1980s, he had put Marty in place as chief hydrogeologist. Marty had the charge, the space, and the prerogatives necessary to establish a rising degree of professional excellence in the geologic site studies contracted to WMI. Complementing Marty’s drive, technical competence, and people working skills was his equally capable immediate engineering supervisor, Gary Williams, performing as corporate manager of environmental compliance.

Marty thrived under the protection, guidance, and support of Gary. The first Sara sole author master achievement was his emergency (night-and-day) compilation of the WMI *Site Assessment Manual*, completed in full draft form in 1987. Marty wrote most of the manual with his Apple computer, on the breakfast-room table of his Park Ridge home, receiving considerable incidental support from wife Terri and their four children. “SAM” came into life as a custom published, three-ring binder constituting the body of standard excellence by which WMI’s consultants were to be judged for acceptability of their product and for future retention.

In dealing with the huge array of practical site characterization problems facing WMI, Marty originated the monumentally useful concept of the *conceptual site geologic model*, which he promoted as the starting point for all manner of site characterization. This was his single greatest innovation and its impact should have been grounds for election to the National Academy of Science. Marty preached and sold the site conceptual model at every instant. May he also be profoundly remembered for this gift to the profession. It is only fair to say, however, that in Britain, the same general concept was coming to life, contemporaneously, as co-created by Peter Fookes, the British “giant” of our profession, though these two gentlemen never met.

Marty wrote SAM to solve WMI’s internal problem with achieving and maintaining quality from its many consultants. Marty thrust SAM forward decisively at WMI, under the Williams concept of standardization. After having been tested as the standard for WMI consultant reports, SAM, the manual, became the manuscript for a monumental effort published in the form of Marty’s two later hardcover manuals (1993 and 2003). In the first (corporate) manual, Marty made liberal use of optically scanned and graphics edited charts and other drawings originally submitted in reports by WMI’s numerous paid consultants. With this new corporate guideline for excellence, Marty and Gary reduced the total number of selected consultants, favoring retention of firms exhibiting the highest degrees of competence, both in corporate philosophy and in quality of staff.

Life was good (and hectic) for the Williams-Sara team at WMI for a decade, until management decided to concentrate its headquarters professional technical staff at the newly acquired RUST Environment & Infrastructure (RE&I). The RE&I concept was to develop and concentrate in-house geological and engineering technical support and to reduce and further control external consulting costs.

Marty was assigned to RE&I in 1994 and was allowed to work his magic there for three years, until the 1997 Wall Street takeover of the company. Almost immediately the Williams and Sara level of attention to environmental excellence fell under new management priorities. Headquarters was moved to Houston, Texas, and both men and many of their supporting staff left the company. The two innovators continued the battle for excellence in other employment, but never with the security, trust and freedom of their original engagements at the “original” Waste Management, Inc.

In 1993, while still at WMI, Marty published a formal, hardcover revision and expansion, which he nicknamed “Son of Sam,” but which was published by CRC Press as *Standard Handbook for Solid and Hazardous Waste Facility Assessments*. Ten years later, Marty made another major revision. So practical and encyclopedic are these last two books that they will remain applicable for several decades into the future.

A natural adjunct to Marty’s drive toward corporate geological standardization was his intense participation (Sara and Neilson, 1992) in the related activities

of the American Society for Testing & Materials (ASTM; now ASTM International. Marty was not wholly enthusiastic about reducing geologic judgment to “standards” (and many of us so agree); which is the “way” of ASTM’s product. His main argument for participation in ASTM deliberations was that the “guidelines” movement was going to “happen anyway,” and that he would try to more positively affect the outcome. Marty achieved this goal by having the special title of *Standard Guide* utilized. In this way Marty gave support to the true professional geological and engineering community in such a way that the advisory nature of the documents would not tend to take on the prescriptive nonprofessional routine of laboratory testing, which is the general nature of ASTM standards.

The “old” (original) WMI, due to its aggressive habit of garbage collection company and landfill acquisitions, was also involved in quite a number of serious hazardous waste cleanup actions, both under the provisions of RCRA (as in compliance actions) and the Superfund law. Of these, Marty’s greatest challenge was in representing the company’s interests, and those of co-RPs (Responsible Parties) for the long-term remedial actions taken at the Denver-Arapaho Disposal Site (“DADS”). This National Priority List (NPL) site of uncontrolled hazardous waste disposal (along with monumentally larger volumes of nonhazardous solid waste) was located at the far southern end of the former Lowry Air Force Base Gunnery Range, in undifferentiated Denver-Dawson Formation Cretaceous marine weak-rock strata. WMI was a later operator of the facility, from 1980 (following others), until the facility was named to the National Priority List in 1983.

Marty took a lead role in coordinating and managing the efforts of the Lowry Coalition of PRPs, including Denver County. He was keen on applying practical expertise in sedimentologic classification as a means to characterizing the widely variable flysch-type lateral variations in formation density and porosity. Many of his lessons learned made their way into the two *Son of Sam* books.

After dispersal of the original ten-year WMI environmental staff, Marty elected to remain in Chicagoland, in the best interests of his family. During this chaotic bid-shopped era of our profession, Marty was principal hydrogeologist at Geomatrix and then Arcadis (the late Geraghty & Miller), and was area manager for the early environmental engineering and science consulting firm of ERM, Inc., at the time of his untimely affliction. Ironically, Williams came to join the firm in January 2006 as part of a new regional expansion plan, and found only Marty’s carefully-maintained empty office, with the company optimistically awaiting his return.

An outstanding feature of Marty’s calling to the profession of engineering geology was his constant willingness to give of time and energy for the benefit of younger members of the profession. The University of Missouri–Rolla asked him to serve on a Board of Review for the then-Geological Engineering Department and he willingly did this, and provided visits and lectures for several years. As a result of this intense presence on the part of WMI, many Rolla geological engi-

neers joined the old company and several outstanding alumni are still with the present company.

“Marty stories” contribute to his legend. He managed his affection for a fine dinner and fine wine only as a personal “reward” for his earned successes of the day. Colleague Doug Coenen (of Oregon Waste Systems, then a WMI subsidiary) recalls a fine dinner at a regionally famous restaurant, The Dalles, in Oregon. Marty had been under the scrutiny of company “bean counters” on account of his travel-meal expenses while on travel status. Marty was torn between this insensitive accountability and his own fine taste. Doug was adroitly handed the huge dinner bill (mostly for a bottle of fine vintage) and, sure enough, had to answer to the bean counters. Doug says that the guff was well worth the evening’s scintillating association with Marty.

During Marty’s life of intense professional activity, he and wife Terri raised their two girls and two boys, and kept a modicum of daily sanity and normality around the Sara home. Marty’s energies were truly boundless; his actor’s good looks were matched with his impeccable dress code (office or field) and he literally never “lost a minute” in life without moving forward. Martin Sara was the “perfect,” perfectly “rounded” example of a practicing member of the profession.

The Sara energies, however, were curbed in his last year of life when it became apparent that an affliction with ALS had begun to curtail this giant’s motion. On that realization, first apparent with speech impediment, Marty withdrew to home care, where elder son Marty, just then the first of the children to graduate from university training, devoted himself to join Terri in full-time care of his father.

So large was Martin Sara’s real image, and so long was his shadow that those who knew him or crossed his path were fortunate in many ways, and we will long remember him and his good deeds.

Lorne G. Everett



Ivan Johnson, P.E., a water and soil consultant in Arvada, Colo., died Aug. 31, 2011. Johnson had been an ASTM International member for more than 50 years, having joined the society in 1942. Over the years, he served on several committees, including D18 on Soil and Rock, D19 on Water; D22 on Air Quality, D34 on Waste Management, D35 on Geosynthetics, E43 on SI Practice, E47 on Biological Effects and Environmental Fate, and E50 on Environmental Assessment, Risk Management and Corrective Action.

Ivan graduated from the University of Nebraska in Lincoln with a B.S. in civil engineering in 1949; he also did graduate studies at the University of Nebraska and received a doctorate degree in geohydrology from the University of Turkey in 1995.

I first spoke with Ivan in 1977 when I was Co-Chairing with Dr Kenneth Schmidt, Past President of AWRA, the development of an AWRA Symposium entitled “Establishment of Water Quality Monitoring Programs” to be held in San Francisco. Ivan was a legend at that time in hydrogeologic training and I asked him who to invite to speak on hydrogeologic techniques. Ivan recommended that I invite Mr. Larry Eccles who was with the USGS to give two key papers. That recommendation from the Biblical figure in our business was enough. The Symposium is credited with being the first “How to” hydrogeologic meeting and spawned a whole industry in hydrogeologic training seminars. At the AWRA meeting David Miller co-founder of Geraghy & Miller/ARCADIS jokingly said: “Lorne we are not going to let you Chair any more meetings because there is nobody in the hallways and we cannot do any marketing.” The next year Geraghy and Miller started their highly successful Hydrogeologic Fundamentals courses. When I joined ASTM, Ivan was ASTM royalty and he would frequently attend my D18.21.02 meetings. He was indefatigable and completely on top of his science. He worked tirelessly at home and produced massive amounts of ASTM guidance. I am honored to dedicate this book to an icon of ASTM and to a man whose life is “the measure” for all who knew him.

A. Ivan Johnson was honored (reprinted with permission from ASTM Standardization News) for outstanding leadership in the development of interdisciplinary

voluntary consensus standards in terminology, mensuration, test methods, and practices, and promotion of their use through his activities in many international and national organizations.

Ivan Johnson was recognized internationally as an authority on soil, rock, water, and their intimate interrelationships within the earth's environment. He had been a prolific author and editor of nearly 100 publications related to these subjects. During his early career with the U.S. Geological Survey (USGS), he was involved with many subsurface exploration and evaluation studies throughout the United States. Johnson organized and supervised the USGS National Hydrologic Lab as well as the USGS National Special Equipment Unit. As staff hydrologist for the 12 state USGS Rocky Mountain Region, he was given responsibility for organizing and subsequently supervising a National Water Resources Training Center.

His next assignment was as assistant chief of the Office of Water Data Coordination, headquartered in the Washington, D.C., area. That office had responsibility for coordination of water resources data banks and data collection activities of more than 30 federal agencies. Following retirement, in 1979, from USGS, he became a consultant to Woodward-Clyde Consultants for five years. He then formed his own firm, A. Ivan Johnson, Inc., specializing in soil and water consulting on projects primarily in foreign countries.

Ivan Johnson was active in ASTM standardization activities for over 50 years. He was involved in Committees D-18 on Soil and Rock; D-19 on Water; D-22 on Sampling and Analysis of Atmospheres; D-34 on Waste Disposal; D-35 on Geotextiles, Geomembranes, and Related Products; E-10 on Nuclear Technology and Applications; E-34 on Occupational Health and Safety; and the Committee on Terminology, including being instrumental in the initiation of new subcommittees and serving six years as chairman of D-18.

Ivan Johnson was chairman of D18 from 1976 to 1982 and D18 vice chairman from 1970 to 1976, as well as a chairman of D18 subcommittees for many years. A member of the ASTM board of directors from 1989 to 1991 and a 1982 Award of Merit winner for his contributions to D18, Johnson received several awards for his service to D18 and ASTM International, including the D18 A. Ivan Johnson Outstanding Achievement Award in 1996, which was renamed in his honor; the William T. Cavanaugh Memorial Award in 1987; the D18 Honorary Committee Member Award in 1984; the Frank W. Reinhart Award in 1983; and D18 Special Service Awards in 2006, 2004 and 1968. Other awards included the U.S. Department of the Interior Meritorious Service Award in 1977, a Special Service Award from the American Water Resources Association in 1973, Engineer of the Year Award from the Professional Engineers of Colorado in 1969 and a U.S. Department of the Interior Merit Award in 1962.

Professionally, Ivan Johnson had been associated with the U.S. Geological Survey for more than 30 years. During that time he organized the USGS National

Hydrologic Laboratory, which provided engineering, geologic and agricultural analyses of soil and rock. In his career and as a consultant he focused on geotechnical and hydrological testing, including soil and rock for engineering purposes, and the development, control and conservation of water resources. Ivan Johnson was a fellow of the American Society of Civil Engineers and of the American Water Resources Association; his other professional memberships included the American Geophysical Union, American Institute of Hydrology, American Society of Agronomy, International Association of Hydrological Sciences, International Society for Soil Mechanics and Foundation Engineering, International Union of Soil Science, International Union of Geodesy and Geophysics. Ivan Johnson contributed to numerous symposia proceedings and wrote or co-authored numerous technical reports and papers.

In my decades with ASTM, Ivan Johnson stands out as the consummate member, mentor, teacher, and chairman. Ivan had grace, warmth, and compassion. Ivan took the time to inspire all who had the good fortune to know and work with him over his 60 years at ASTM.

Lorne G. Everett

Overview and Summary

The symposium focused on newly released critical continuous soil gas monitoring data associates with residential and industrial activity around the world. Multiple representatives from the United Kingdom, Canada, Germany, Brazil, etc., participated in the Symposium. From oil and gas companies, chemical companies through small industrial sites, there is a growing need to understand and mitigate worst case/explosive or high human health risk conditions. Dry cleaners, gas stations, refineries, fracking sites, landfills, landfill energy systems, machine shops, etc., all can exhibit Vapor Intrusion (VI) risk. Often driven by litigation, the interest in VI into homes and buildings has skyrocketed. Groundwater clean-up costs are dwarfed by the potential for class action VI suits. Recent dynamic risk observations pose serious implications about conventional approaches, best management practices, due diligence and formerly closed sites, and create a need to identify and understand site-specific conditions that warrant continuous monitoring. As such, several regulatory entities are now advocating for continuous VI monitoring and formerly closed sites with no further action letters are being reopened. The forthcoming reduction in the MCL's of TCE and its designation as a human carcinogen will have a dramatic effect on environmental site characterization, remediation and litigation.

In the disciplines associated with environmental assessment, restoration and monitoring, paradigm shifts based on practical realizations, observations and new technologies occur every decade or so. In the late 1980s, practitioners realized that “plume chasing” by blindly installing monitoring wells to determine groundwater solute distributions was inefficient and represented an iterative approach that was economically unsustainable. For instance, every well installation phase resulted in growing plume “footprints” in map view until practitioners finally reached the downgradient end of the contaminated zone with “sentry wells”. However, even these wells could eventually display unacceptable solute concentrations as the plume continued to advance. In the mid-90s, acceptance of field analytical approaches allowed for a “screening” step prior to committing to long-term monitoring well network installations. Eventually, the Triad approach was developed through consensus, endorsed, and became more commonplace for practitioners aiming to reduce time and costs. This allowed for the use of field analytical techniques to not only determine where contaminants were located, but to design long-term monitoring networks by employing a dynamic work plan driven by observations made during critical survey phases and rapid consensus among key stakeholders and field personnel.

With the recent advent of sensor based monitoring (sometimes referred to as “The New Triad”), new insight regarding environmental conditions and dynamics have resulted in the next paradigm shift; one that recognizes that there

can be an interplay between specific risk parameters, natural phenomenon and anthropogenic activities. More specifically, new multi-parameter sensor technologies have been used to track key attributes and offer the practitioner the ability to understand correlations between volatile subsurface contaminants, oxygen and atmospheric pressure. For instance, vapor intrusion (VI) encroachment risks can be depressed during high pressure cycles, which is when weather is often ideal for field campaigns. Other key factors leading to dynamic risk include tidal influence, lunar forces, precipitation, soil moisture, and anthropogenic activities such as HVAC systems and remediation efforts that can impart change in the shallow subsurface.

This symposium was established because over the past several years practitioners in the U.S., Europe, and the South Pacific began observing dynamic methane and halogenated hydrocarbon concentrations and geospatial distributions. Furthermore, these changes were correlated with changes in atmospheric pressure. While it has been well known that barometric pumping occurs in the vadose zone, for some peculiar reason, this was not initially considered during VI surveys used as due diligence during real property transactions and related legal cases. Furthermore, the traditional soil vapor survey, which was originally designed to be a field screening tool to identify sources of vadose zone and groundwater contamination, became the “workhorse” of the environmental consulting community to determine whether VI risks were relevant. Given that the site characterization community is now documenting that these risks can be dynamic, the implications have become profound. For starters, while risk dynamics may not always occur, recognition of the potential for dynamic risk implies that sites where soil vapor surveys were performed in the past may need to be revisited and re-evaluated using continuous monitoring technologies. In addition, now that sensors exist to monitor for VI risk, remediation systems can be deployed and triggered when conditions are warranted due to threshold exceedances. Furthermore, in light of recent EPA revelations regarding low level acute TCE exposures for pregnant women in their first trimester (often before they know they are pregnant), continuous air monitoring and automated mitigation should be mandatory for buildings located in areas where VI is suspected.

Clearly, there is a need to change policy through ASTM and related channels, and to ensure the safety of building inhabitants, reduce the risk of legal exposure, and to promote more accurate environmental field assessment activities. For instance, much like field screening was approved to help improve the groundwater monitoring well network design in the mid-90s, a preliminary evaluation for VI risk dynamics using continuous monitoring through several barometric cycles can be employed prior to performing a comprehensive soil vapor survey with traditional methods to determine whether a “floating baseline” exists. This will result in greater conceptual site model accuracy and safety. Integration of dynamic fluxes with temporally based exposure models also becomes possible. This type of risk assessment approach is currently being required in parts of Europe and Australia and should be considered in the US.

Until required by regulation or forced by legal action, there will most likely continue to be resistance to the suggestion that VI investigations should include continuous soil vapor monitoring to determine whether risks are dynamic, and if so, to evaluate worst-case scenarios. However, the legal community and early adopters in the regulatory and consulting communities have already started to take notice, and as a result, the trend towards continuous VI monitoring is gaining momentum. It is our hope that support for research to identify and evaluate conditions that would (and would not) result in dynamic risk conditions will be forthcoming. Furthermore, we remain hopeful that regulatory and industry adoption of the concepts presented in these following chapters can occur rapidly, as there may be thousands of sites throughout the globe for which health risks posed by VI have not been characterized for spatio-temporal dynamics, and these risks may therefore not be adequately addressed.

Paper Summaries

The opening paper entitled *The Use of Continuous Monitoring in Detection and Prediction of Worst Case Risk Parameters* by Peter M. Morris, T. Smith and S. Boulton, Ion Science Cambridge, UK, presents why it has been recently accepted that soil gas concentrations can be highly variable and has serious consequences for monitoring programmes and subsequent decision making. This paper highlights the uncertainty surrounding traditional spot sampling techniques and demonstrates how continuous monitoring significantly improves the detection and prediction of ground gas regime. It is likely this work will play a part in repositioning legislative requirements whilst at the same time producing a more cost effective approach.

Many environmental parameters show high temporal variability; therefore, their representative measurement requires multiple measurements. In the case of ground-gas monitoring, flaws in the existing multiple measurement approach have been identified in the literature and are subject to continuing correction. The two underlying causes of these flaws are that, quantification of risk requires accurate measurement of ground-gas concentration and of ground-gas fluxes both of which are likely to be temporally variable and neither is measured directly. The concentration of gas in the ground is inferred from periodic (weekly - monthly) sampling of gas accumulated within a borehole and the flow of gas from the ground is inferred from periodic measurement of gas flow from the same borehole. The relationships these inferences are based upon will be highly site-specific and time-dependent. This paper shows how the impact of these can be reduced by continuous monitoring, thereby reducing uncertainties in ground-gas risk assessment. To this end the paper shows how it is first necessary to understand the general principles of current ground-gas risk assessment.

The paper entitled: *Automated Continuous Monitoring and Observation of Dynamic Subsurface Vapor Contaminant Concentrations*, by Mark L. Kram (Groundswell Technologies, Inc.), Peter Morris (Ion Science, Inc.) and Lorne G. Everett

(L. Everett & Associates, LLC) is a seminal paper which describes a field effort whereby a network of real-time continuous soil vapor monitoring devices was deployed to monitor for potential explosion hazards caused by vapor intrusion. During a routine quality control review of the automated data visualization platform performance, Dr. Kram first observed that the geospatial distribution of methane risk levels was dynamic for this site, and that dramatic changes in risk can occur over very short timeframes. Furthermore, he recognized that there was an inverse correlation between methane and oxygen for several of the data collection points, and that reversals were temporally consistent with changes in atmospheric pressure. These observations served as a key justification for the coordination of this symposium, as they have profound impacts on real property transfers, indoor air quality, health and safety issues, and future protocol related to risk assessment and mitigation.

The paper entitled: Proton Transfer Reaction Mass Spectrometry as a Real-Time Method for Continuous Organic Vapor Detection in Soil Gas and Ambient Air by Joseph Sears, RJLee Group, Pasco, WA, USA; Jacob McCoskey, Washington River Protection Solutions, Richland, WA, USA; Todd Rogers, Columbia Basin College, Pasco WA, USA; Larry Lockrem, LLL GeoChem, Kennewick, WA, USA; Heather Watts, Len Pingel, Kris Kuhl-Klinger and James Conca, RJLee Group, Pasco, WA, USA, describes Proton Transfer Reaction Mass Spectrometry as a relatively new analytical technique ideally suited for real-time measurements of volatile organic compounds, including groundwater releases into vadose zones, building vapor intrusion from soils, and above ground vapor releases. Using H_3O^+ as a reagent ion, a proton transfers to compounds with a proton affinity greater than water, e.g., acetone, BTEX, trichloroethylene, tetrachloroethylene, and many others present in soil gas or ambient air. Ultrapure water vapor flows into a hollow cathode where H^+ , H_2^+ , OH^+ , and H_2O^+ are produced and then glide into a secondary drift tube reacting with H_2O to produce H_3O^+ which then protonates VOCs in the ambient air being drawn into the drift tube at adjustable rates. Interfering ions such as NO^+ , O_2^+ , and water clusters are minimized by specifically tuning the ion source. There are no reactions with the primary components of air, such as N_2 , O_2 , Ar, and CO_2 . For those VOCs not protonated by H_3O^+ , such as methane, NO^+ or O_2^+ can be used as the reagent gas. Samples do not need to be prepared or pre-concentrated and there is no carrier gas. Air samples are introduced directly into the drift tube allowing for dynamic pore space sampling or VOC flux measurements. Long sampling lines can be used to transport the sample from the source to the instrument with no sensitivity loss. A calibration blend of select VOC's in air or other source gas is delivered to calculate the normalized sensitivity and to calculate an ambient air or soil gas concentration, allowing real time measurement of VOC fluxes at mid to low parts per trillion volume. The instrument is relatively small, requires little maintenance and operating costs, allowing the instrument to be emplaced in a mobile laboratory along with other complimentary instruments such as GC-MS.

The paper entitled: Vapor Intrusion Risk Assessment with an Innovative Mobile GC-System by M . Bittens, Escola Politecnica da Universidade de São Paulo, São Paulo, Brazil; B. Seelhorst and M. Mondin, Nickol do Brasil Ltda, Cotia, Brazil; and R. Meye, Meta Messtechnische Systeme GmbH, Dresden, Germany, focuses on a mobile soil gas testing system. Assessing quantitatively vapor intrusion is a great challenge due to the high variability of environmental conditions that affect the processes involved in the migration of chlorinated volatile organic compounds (CVOCs) from the subsurface into enclosed spaces. A new developed GC system that is using a thermal ionization detector (TID) allows an integrated on-site measurement of resulting indoor air concentrations simulated in a flux chamber. The TID detects selectively chlorinated compounds at a low concentration level which is typically for vapor intrusion scenarios. The analysis system does not require any enrichment of samples and delivers the results rapidly. After conversion into the corresponding real flux rates, the vapor intrusion can be modeled, e.g., with the Johnson and Ettinger model, on the basis of more realistic data. The introduced flux based approach overcomes the currently still existing gap of knowledge and process understanding of the contaminant transfer from the subsurface through base slabs of buildings, which is usually being characterized by heuristic or best-guess parameters.

The paper entitled Measurements of Natural Gas Emission Rates from Below Pipelines by K. Farrag, Gas Technology Institute, Des Plaines IL., presents the procedure and field measurements of methane emissions from underground pipeline leaks. The procedure consisted of capturing the gas emissions at the ground surface rather than excavating and isolating the leaking pipe. This approach allowed for performing significantly larger number of tests without the need to excavate the soil, interrupt the service to the customers, and cut and isolate the pipe sections for leak measurements. The field measurements were performed at gas utility sites in various cities using the surface measurement method along with the measurements obtained from excavating and isolating the pipe. The field data provided new estimates for the methane emission from gas pipe leaks.

The Paper entitled: Measuring Compound Concentrations Using Time-Integrated Passive Soil Gas Samplers by Jay W. Hodny, Ph.D., James E. Whetzel, and Harry S. Anderson, W. L. Gore & Associates, Inc., Elkton, MD USA notes that soil gas sampling has been performed for decades in environmental programs, where the results are used to focus subsequent more invasive and expensive sampling, to evaluate the performance of remedial systems, or to identify new releases. More recently, soil gas sampling has become an integral part in evaluating the potential for intrusion of gas-phase volatile and semi-volatile compounds into confined structures. Conventional soil gas sampling utilizes active or passive methods. Active methods force an extraction of soil gas from the subsurface environment at a point in time, when site conditions do not limit or preclude the gas extraction. Passive methods rely on natural, gradient diffusion of gas-phase compounds, through the soil pore space, to the sampler for continuous

collection. Passive methods are simpler to use, allow for sampling under a wider range of site conditions, and have increased sensitivity to lower concentrations of a broader range of compounds, and lessen the chance of field errors through minimal sample handling, when compared to active methods. While passive soil gas sampling may not be considered continuous sampling in the strictest sense, the procedure measures gas-phase compounds in a continuous, time-integrated manner, during the length of exposure. Data from passive soil gas sampling have been considered semi-quantitative (measured mass/compound/sampler) rather than quantitative (measured mass/measured volume) as with active methods. However, workplace air concentrations have been measured for decades in industrial hygiene programs using sorbent-based, passive samplers (i.e., dosimeters). With careful application of the sampling rate procedures, and accounting for the resistance to gas diffusion in the soil environment, soil gas concentrations can be reported using a sorbent-based, passive sampler. The paper discusses the GORE® Module, a highly versatile, passive, sorbent-based soil gas sampler and the procedures in place that allow for reporting quantitative soil gas data from the sampler. The application of passive sampling presented herein, will be elaborated on in the forthcoming ASTM Standard Guide for Determining Concentration Values from Groundwater, Air and Soil Gas Using Adsorbent-Based, Passive Samplers.

The paper entitled: The Importance of Soil Moisture for Insitu Gas Surveying and Plume Assessment by Whitney Skaling , and Dr. Ali Farsad - Soilmoisture Equipment Corp, Goleta, CA, USA describes how to establish responsible values for finding subsurface ground water contamination or other volatile contaminant plumes, by taking into account the native pore size structure and current pore water (soil moisture) status. Water-pore relationships can change gas/pore access routes and speeds from source to the surface. Pore constriction caused by variable soil moisture levels can alter flow and migration paths. Therefore, the assumed concentration topology findings will map differently as it affects gas egress from plume source to the surface through surrounding soil/rock lithology. It is then necessary to normalize sampled values to account for these possible changes in subsurface as these changing soil moisture conditions will directly or indirectly affect transfer rates and direction of volatiles. The pore water distribution through the surrounding lithological profiles is the most important restrictive variable element. Knowing and monitoring soil moisture over the sampling period will be crucial to any normalized gas sample volume calculations and their accumulated mass or % volume over time. If not accounted for in a gas sampling protocol, variable soil moisture conditions can create biased topology concentrations, creating offsets in location findings and/or migration patterns.

The paper entitled: Soil Gas Sampling with Direct Push and Hand Sampling Equipment by Thomas D. Dalzell, AMS Samplers, American Falls Idaho, USA describes how lack of proper preparation and planning leads to poor performance! The purpose of this paper is to list/outline the crucial steps and considerations, at a minimum, that should be taken in to account, every time, to develop and conduct a complete and successful soil gas sampling plan and vapor intrusion

monitoring procedure. Soil gas samples are collected using a variety of sample collection techniques with tooling associated with direct push drilling technology (direct push), conventional drilling, or manual-driven hand-sampling equipment for soil gas surveys. Attention and adherence to every detail is very important in soil gas sampling and sub-slab vapor intrusion monitoring.

The paper entitled: Vapor Migration Assessment for a Chlorinated Contaminated Site via Induced Flux Measurement by André Tartre, Envir-Eau, Montreal Canada, provides a novel practical approach to soil gas sampling. The dynamic of the “soil-liquid-gas” system in the vadose zone makes active sampling relevant only at the exact location and during the specific time period of the collection. The changing nature of the soil atmosphere represents a constant challenge for the assessment of long-term conditions. This paper proposes three modifications to the standard soil atmosphere sampling procedure to optimize monitoring when certain conditions are met. The first proposed modification concerns the sampling flow rate. During active sampling, movement of the soil atmosphere by convective flow through soil pore space causes changes in the gas phase concentrations. To obtain a sample “quite representative” of the soil atmosphere under natural conditions, low flow sampling should be used in most circumstances, and range between 40 to 70 ml per minute. The second proposed modification considers the difference between gas and vapor during soil atmosphere sampling. The distinction between these two types of compounds is important when assessing soil atmosphere, since their behaviors are quite different. All sampling of the soil atmosphere should be conducted for both gas and vapor, and at a minimum include the measurement of oxygen, to verify the absence of atmospheric infiltration nearby the sampling area. Finally this paper describes the induced flux method, an innovative sampling technique which assesses soil gas and vapor migration potential. Active soil atmosphere sampling coupled with induced flux measurements represent an excellent alternative to long-term monitoring in some circumstances. The induced flux method evaluates “worst case scenario” at specific locations, and provides much more information during a single sampling event than concentrations of the soil atmosphere alone.

The paper entitled: Continuous Monitoring of Soil Gas by PID/FID Analyzers by Dr. John N. Driscoll, PID Analyzers, Sandwich, MA USA noted how the photoionization detector (PID) has been used for monitoring carbon beds in pump and treat operations for many years. One of the major applications has been the cleanup of gasoline from groundwater and soil. At a contaminated site (gasoline station), a portable analyzer was used to check the VOC concentration once per week. The labor cost was too high so a Model 112 PID in a NEMA enclosure was selected to continuously monitor the output of carbon beds at a gasoline station. The analyzer was set to alarm and turn off the pump when the concentration reached 4 ppm of hexane. The alarm also triggered a cell phone call to the office to indicate a problem. An 8GB USB data logger was used to store the concentration as a function of time and the site was visited only once a month to collect

data and calibrate the analyzer. To meet the very low action level set by the local environmental authorities, only a continuous analyzer could be used. A weekly monitoring operation was not an option for the local authorities.

Another application involves leaking of VOC's into basements of buildings. Leaks can come from contaminated soil or groundwater or even from landfills. For the evaluation of basements in homes, the HNU PID PI101 was first used to evaluate health problems in houses at the Love Canal (later a Superfund Site) in 1975 by the NY Dept. of Health. Today's instruments (DL102 or 112) can continuously monitor and log data over longer periods of time to evaluate potential sources of leaks and recommend the type of remediation. An 11.7 eV lamp can be used to detect many of the low molecular weight (MW) chlorinated hydrocarbons (HC) found in ground water and soil and a difference in the 10.6/11.7 ratio could alert the user to the presence of low MW chlorinated HC. The datalogger can store data for many months and easily download the data to a PC. A Model 112 can be equipped with a flame ionization detector (FID) *and* a PID so that methane and other VOC's can be detected in the same analyzer. The 112 can be connected directly to the internet allowing remote users to view the data with any PC in their office. Some of the advantages of continuous monitoring vs spot checking were also discussed.

Symposium Observations and Recommendations

Current regulations and protocol focus on single time step assessment campaigns, as it has been assumed that subsurface conditions are static;

Recent findings at more than 60 sites over the past 18 months suggest dynamic risk conditions can exist;

Correlations between risk and barometric pumping, soil moisture, tidal impacts, groundwater extractions and variable subsurface vapor flows are possible;

There is an immediate need for incorporation of newer detection and data management methods into initial field assessment protocol and regulations/guidance;

There is an immediate need for incorporation of newer detection and data management methods into remediation design and performance assessment strategies;

Since we now know it is possible to encounter dynamic VI risks, in order to avoid missing worst case scenarios, we recommend that continuous monitoring be performed for at least a few selected site locations (e.g., data collection points, DCPs) prior to implementation of an alternative non-continuous geospatial soil vapor survey campaign in the encroachment zone;

Continuous monitoring field campaigns should be performed when barometric pressure changes are anticipated so that practitioners can estab-

lish whether risks are dynamic through a range of atmospheric pressure conditions;

If practitioners do not have the luxury or flexibility in their field deployment schedule, then an alternative strategy for testing worst case scenarios would be when a low pressure dominates the site region;

Dynamic soil gas behavior has been recorded in both petroleum hydrocarbon (BTEX/Methane) and chlorinated hydrocarbon (PCE/TCE) sites;

Changes in soil gas concentrations can be very rapid, and can fluctuate multiple times within a day;

Continuous soil gas monitoring of both petroleum VOC's (methane/BTEX) and some chlorinated VOC's (in the ppt range) are now available, although more specific ion sensors need to be developed;

Soil moisture can significantly impact soil gas concentrations and ranges, changes over time and space, regional vapor flow;

Soil moisture impacts can be observed under an individual building or home, be linked to vegetation cover, topography, soil type and location of building downspouts;

- Other factors to consider include time since most recent precipitation, infiltration wetting front, hysteresis, lithology, evapotranspiration, temperature and tidal fluctuations (e.g., when near shorelines), industrial blowers, etc.

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