

# VAPOR INTRUSION – EPA’S NEW REGULATORY INITIATIVE AND IMPLICATIONS FOR INDUSTRY<sup>1</sup>

By

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## I. OVERVIEW

By the time of this seminar, the U.S. Environmental Protection Agency (EPA) Office for Solid Waste and Emergency Response (OSWER) will likely have published in the Federal Register new proposed guidance for addressing vapor intrusion at EPA lead sites. Based on recent cases in Colorado and a few other states, this new focus on vapor intrusion may lead to significant costs and liabilities for responsible parties at sites across the country, including exposure to class action lawsuits. Many state agencies appear to be following (or in some cases, preceding) EPA’s efforts in this area. Environmental attorneys may wish to evaluate the potential liabilities this pathway may pose to their clients and recommend steps to manage or reduce these risks.

### A. What is Vapor Intrusion?

Vapor intrusion is the migration of vapors from the subsurface into buildings. Sources of vapor intrusion include contaminated groundwater or soil, buried wastes, and leaking underground storage tanks. Compounds must be “volatile” in order to cause vapor intrusion; examples include benzene (usually associated with gasoline) and chlorinated solvents, such as trichloroethylene (TCE). Vapors from natural geologic materials may also enter buildings; the most common example is radon gas.

### B. Past Regulatory Requirements

While the scientific and regulatory communities have been aware of the theoretical possibility of vapor intrusion for over two decades, until very recently vapor intrusion was not considered to be a pathway of significant concern. The exceptions were radon, which became a focus of attention in the 1980’s; gasoline vapors associated with large fuel leaks, which could accumulate in overlying buildings and cause explosions; methane migrating from landfills, which could also cause explosions; and in rare cases, landfill leachate seeping into basements. Beyond these easily recognized conditions, however, little attention has been paid to the vapor intrusion pathway.

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<sup>1</sup> Presented at the ABA Litigation Section, Environmental Litigation CLE Seminar in Snowmass, CO, January 18, 2003.

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The historic lack of focus on vapor intrusion is evident by its absence from federal environmental laws and regulations. No requirements for evaluation of vapor intrusion have been or currently are provided in RCRA Subtitle C regulations<sup>3</sup> or Corrective Action guidance<sup>4</sup>, or in the National Contingency Plan (NCP)<sup>5</sup>, the related Remedial Investigation and Feasibility Study guidance<sup>6</sup>, or the Hazard Ranking System<sup>7</sup>, used to identify new sites for the National Priorities List (NPL).

A few obscure Superfund guidance documents began addressing the vapor intrusion pathway in the early 1990's<sup>8</sup>; however, vapor intrusion was still not addressed in the principal RI/FS and corrective action guidance documents under the RCRA and Superfund programs, respectively.

More attention was paid to the vapor intrusion pathway with the advent of "risk-based corrective action", or RBCA. The RBCA concept was first developed to steer cleanup requirements away from set standards, such as the drinking water Maximum Contaminant Levels (MCLs), and toward cleanup standards that were based on actual risk to human health and the environment. In order to apply the RBCA concept, risk assessments were required to develop the appropriate cleanup levels. This in turn led to a focus on the various pathways by which people could theoretically be exposed to compounds of concern, including the vapor intrusion pathway.

RBCA was first applied to leaking underground storage tank (UST) sites, because natural attenuation of benzene and other petroleum constituents generally limited the distance that these compounds could travel. The American Society for Testing and Materials (ASTM) developed the first widely used guide for applying RBCA principles at petroleum release sites in 1994<sup>9</sup>, which included detailed equations for estimating indoor air concentrations of volatile compounds found in soil or groundwater, based on a simplified form of the Johnson & Ettinger (1991)<sup>10</sup> predictive model. EPA embraced this approach for UST cleanups and over the past ten years various state agencies have adopted the RBCA concept in their UST regulations and guidance, including equations or standards based on varying forms of the Johnson & Ettinger (1991) model.

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<sup>3</sup> 40 CFR Part 264.101

<sup>4</sup> *RCRA Corrective Action Plan* (May 1994) and *Interim Final; RCRA Facility Investigation (RFI) Guidance* (May 1989)

<sup>5</sup> 40 CFR Part 300

<sup>6</sup> *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final*, OSWER Directive 9355.3-01, October 1988.

<sup>7</sup> *Hazard Ranking System*, Appendix A to 40 CFR Part 300, December 14, 1990

<sup>8</sup> EPA 1992, *Assessing Potential Indoor Air Impacts for Superfund Sites*, EPA-451/R92-002; EPA 1993, *Options for Developing and Evaluating Mitigation Strategies for Indoor Air Impacts at CERCLA Sites*, EPA-451/R-93-012

<sup>9</sup> ASTM E 38 - 94. *Emergency Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites*. Later finalized as E 1739 - 95, *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*.

<sup>10</sup> Johnson, P.C. and R.A. Ettinger, 1991. *Heuristic Model for the Intrusion Rate of Contaminant Vapors into Buildings*. *Environ. Sci. Technol.* 25(8). 1445-1452.

In general, the application of the Johnson & Ettinger (1991) model to petroleum compounds was found to be conservative because these compounds biodegrade fairly rapidly in the subsurface, attenuating impacts, if any, on the indoor air of overlying buildings<sup>11</sup>. As a result, there was still a lack of any broad focus on the vapor intrusion pathway for other compounds, such as chlorinated solvents.

The exception to this lack of focus was a handful of states that developed broader requirements to evaluate the vapor intrusion pathway at groundwater contamination sites in the mid to late 1990's, including Massachusetts<sup>12</sup>, Connecticut<sup>13</sup>, and Michigan<sup>14</sup>. These regulations consider the vapor intrusion pathway using an "attenuation factor" for predicting potential indoor air concentrations based on groundwater concentrations. However, the application of these standards was often limited by the detection limit capabilities of standard commercial laboratories and estimates of typical indoor "background" levels for many compounds. Further, application of the standards were generally not required if the depth to groundwater exceeded 15 feet. As a result, these early vapor intrusion regulations did not trigger wide spread concern over the pathway.

At the federal level, focus on vapor intrusion broadened with publication of the EPA Superfund Soil Screening Guidance<sup>15</sup> in July 1996, which provides generic soil screening levels for most volatile organic compounds and provided more site-specific equations for evaluating the groundwater to indoor air pathway. In addition, ASTM also broadened its application of risk-based corrective action beyond just petroleum releases in 1998<sup>16</sup>.

In summary, guidance on evaluation of the vapor intrusion pathway was relatively obscure until the mid to late 1990's, with the advent of the ASTM risk-based corrective action guidance in 1994 (for petroleum) and 1998 (other volatile compounds), the EPA Soil Screening Guidance in 1996, and the requirements of a small number of states, such as Massachusetts. Evaluation of vapor intrusion, however, was not and (at the time of writing) is still not required by any federal laws or regulations.

### C. EPA's New Vapor Intrusion Initiative

Case history experience in Colorado in the late 1990's led to greater national focus on the vapor intrusion pathway, when two sites<sup>17</sup> with chlorinated solvent plumes in groundwater were found to have contributed to solvent concentrations in the indoor air of several dozen residential homes and apartments. Although the plumes at both sites extended off-site for some distance,

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<sup>11</sup> Johnson, P.C., R.L. Johnson, and M.W. Kemblowski, 1999. *Assessing the Significance of Vapor Migration to Enclosed-Spaces on a Site-Specific Basis*, Jn. of Soil Contamination, 8 (3). 389-421.

<sup>12</sup> Massachusetts Contingency Plan, 310 CMR 40

<sup>13</sup> Regulation of Connecticut Department of Environmental Protection, Remediation Standard, Sections 22 through 133.

<sup>14</sup> Michigan Department of Environmental Quality, General Revision Rules R299.5714

<sup>15</sup> *Soil Screening Guidance: User's Guide*, EPA540/R-96/018 July 1996

<sup>16</sup> ASTM PS 104-98, *Standard Provisional Guide for Risk-Based Corrective Action*, July 1998.

<sup>17</sup> The Colorado Department of Transportation Materials Testing Laboratory site, and the Redfield Rife Scopes, Inc. site.

neither the solvent concentrations in groundwater nor the circumstances of the releases were very exceptional – similar groundwater plumes are likely to exist at hundreds of sites across the country.

Meanwhile, in response to the Government Performance and Results Act of 1993 (GPRA)<sup>18</sup>, the EPA RCRA corrective action program developed environmental indicators (EI's) to gauge its progress at RCRA corrective action sites. While developing EI guidance in 1998, EPA became aware of the vapor intrusion work and experience in Colorado and included specific mention of vapor intrusion as a potential pathway of exposure on EI forms published in 1999. These forms or guidance required regulators to make judgments as to whether indoor could reasonably be suspected to be contaminated, who the potential receptors might be, whether these exposures could be significant, and whether or not they were within acceptable limits on a fixed list of 1714 RCRA corrective action facilities nation wide.

A special session on Vapor Intrusion was held in Washington, D.C. in August 2000, where experts in the field were gathered together to help educate EPA and state officials on the pathway, including advice on how best to evaluate sites for vapor intrusion. Most of the available real world knowledge was based on the Redfield site (presented by the senior author), and the nearby Colorado Department of Transportation (CDOT) Materials Testing Laboratory site. Vapor intrusion thus became a major topic of discussion within the RCRA program and a major topic of EPA National RCRA Meetings.

The eventual outcome of this new focus by EPA was the development of guidance on the evaluation of vapor intrusion at EPA sites by OSWER, discussed in the following section.

## II. EPA'S NEW VAPOR INTRUSION GUIDANCE

At the time of writing, EPA expected to publish (for public comment) the OSWER guidance on the evaluation of vapor intrusion in the Federal Register in the near future. The following discussion is based on the draft guidance<sup>19</sup> and discussions with guidance authors.

In 2001, the Corrective Action Branch of the Office of Solid Waste developed draft supplemental guidance to help regulators make vapor intrusion/indoor air determinations at RCRA corrective action facilities, as required by the EI guidance<sup>20</sup>. After this draft was produced, OSWER decided that the guidance should also be applicable to the Superfund program. A more widely based work group was formed, adding Superfund staff and more state programs, resulting in the current draft OSWER guidance document.

The purpose of the guidance is to provide regulators and potentially responsible parties consistent procedures for screening, prioritizing, and evaluating sites for vapor intrusion

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<sup>18</sup> Public Law 103-62.

<sup>19</sup> The draft OSWER guidance was presented by Dr. Helen Dawson of Region 8 at the Colorado Hazardous Waste Management Society workshop on vapor intrusion on October 8, 2002.

<sup>20</sup> The 2001 draft document was produced for public comment and can be found at: [www.epa.gov/correctiveaction/eis/vapor/vapor.pdf](http://www.epa.gov/correctiveaction/eis/vapor/vapor.pdf).

potential. The guidance, organized in the form of “questions”, leads the user through up to three tiers of evaluation. The first tier establishes whether compounds of sufficient volatility and toxicity are present in soil or groundwater within 100 feet of inhabited buildings. If present, the second tier compares groundwater and soil vapor concentrations to generic screening levels, based on assumed “attenuation factors” or reductions in concentration as vapors move from the groundwater table, to soils immediately below the building, to the indoor air. Screening levels for  $10^{-4}$ ,  $10^{-5}$ , and  $10^{-6}$  risk levels are provided: it is up to the lead agency to determine which risk level is appropriate for taking further action. The screening levels for groundwater and soil vapor concentrations may be increased by a factor of up to 50, based on the depth to groundwater and soil type. Finally, if the screening levels are exceeded, the third tier of evaluation requires more site-specific testing, such as indoor air tests and subslab vapor measurements.

EPA considers the guidance screening levels to be conservative, with a greater likelihood of false positives than false negatives. However, it reserves the right to alter the screening levels over time, based on improved case history data. The guidance sets the screening level at the MCL for compounds where the screening level formulae would set a level below the MCL.

### III. IMPLICATIONS FOR INDUSTRY

The new EPA focus on vapor intrusion, including the draft guidance, may have serious implications for current and previous owners and operators of sites where groundwater is impacted by volatile organic compounds (VOCs), including evaluation requirements, potential indoor air investigation and mitigation costs, and more stringent groundwater remediation requirements.

#### A. Requirement to Evaluate Sites

Evaluation of the vapor intrusion pathway will likely be required in the near future at all EPA sites and many state sites where VOCs impact groundwater. In some cases, agencies may reopen sites where groundwater remediation decisions were previously made without considering the vapor intrusion pathway. This may include sites where no further action is currently required, based solely on the low potential to impact drinking water resources.

Done properly, a large number of sites should be eliminated from further concern based on a relatively simple evaluation of existing data. However, up-to-date knowledge and experience with this pathway are so limited, amongst both regulators and technical consultants, that the potential for overly conservative decisions and unnecessary investigations is significant.

The costs of any additional investigations required to evaluate vapor intrusion potential can become significant. Unless modeling using groundwater or soil vapor data can convincingly rule out the potential for indoor air impacts<sup>21</sup>, indoor air tests are likely to be required, increasing both the costs and profile of the investigation. A single indoor air test at state-of-the-art

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<sup>21</sup> There is significant controversy regarding the accuracy and precision of vapor intrusion models; e.g., see presentations and discussion at the special sessions on vapor intrusion of the EPA 2000 and 2002 RCRA National Meetings, Washington, D.C.

detection limits costs approximately \$500<sup>22</sup>, not including the cost of securing access agreements from each building owner and scheduling of the tests (which require two visits, to drop off and pick up the canisters).

#### B. Indoor Air Mitigation Costs & Liabilities

Fortunately, the direct costs of mitigating indoor air impacts are not high. In most cases, carefully installed standard radon venting systems will reduce indoor air concentrations below typical action levels<sup>23</sup>, at a cost of approximately \$1200 to \$1500 for typical residential homes<sup>24</sup>, and approximately \$2 per square foot (of area requiring remediation) for larger commercial buildings.

Unfortunately, indirect costs can be significant, including requirements for on-going performance monitoring, electricity, and community relations. In some cases, only one indoor air test is required after installation of the venting system to show that it is working. More often, however, repeated tests are required to show that the system can achieve action levels during all seasons and under varying conditions.

Finally, indoor air impacts may lead to class action lawsuits with significant damage claims.

#### C. Potential Increased Groundwater Remediation Costs

Vapor intrusion impacts may also increase the cost of groundwater remediation. While source containment and natural attenuation of off-site groundwater plumes may be sufficient to protect groundwater resources, EPA and some state agencies may require more active off-site remedial action when vapor intrusion is involved.

### IV. KEY TECHNICAL ISSUES

Site owner/operators and attorneys facing vapor intrusion issues should be aware of several key technical issues that could have a significant impact on the reliability of data, evaluation costs, and whether or not mitigation is required.

#### A. Vapor Intrusion Modeling

There is significant controversy regarding the ability of numeric models (e.g., the Johnson & Ettinger 1991 model) to accurately and precisely predict indoor air concentrations, based on groundwater or soil vapor concentrations. Validation efforts using real world data indicate that considerable care must be exercised when using models, as the results may easily

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<sup>22</sup> Laboratory analytical fees, canister and regulatory rental, and labor costs associated with installing, retrieving, and handling canisters.

<sup>23</sup> see Folkes, D and D. Kurz (2002), *Efficacy of Sub-Slab Depressurization for Mitigation of Vapor Intrusion of Chlorinated Organic Compounds*, 9<sup>th</sup> Int. Conf. on Indoor Air, Monterey, CA.

<sup>24</sup> Including electrical and mechanical permit costs.

over or under predict actual concentrations. As a result, EPA used conservative assumptions to develop groundwater and soil vapor screening levels in the proposed OSWER guidance, based on the Johnson & Ettinger (1991) model. In many cases, screening levels were predicted to be lower than the MCL; however, the MCL was set as the lower limit for screening purposes.

#### B. Indoor Air Test Method

Special laboratory tests are often necessary to achieve the very low detection limits required by many chlorinated solvent indoor air action levels. Only a handful of laboratories in the country have been approved by the state of Colorado (one of the leading states in the area of vapor intrusion) to these tests for solvents. Requirements include use of EPA Method TO-15 for chlorinated solvents, high-resolution analyses, special equipment tuning techniques, and 6-liter canisters to collect sufficient sample volume. Canisters must be cleaned and tested before use to ensure that residual contamination from prior tests do not impact test results.

Failure to follow state-of-the-art techniques may lead to false positives, due to laboratory contamination, canister contamination, or equipment imprecision.

#### C. Background Concentrations

Many household products, including cleaners, polishes, and adhesives, contain chlorinated solvents, such as TCE, PCE, and TCA. Use and storage of these products results in background levels of solvents, sometimes exceeding health-based action levels<sup>25,26</sup>. Unless the presence of these background levels is identified and quantified to the satisfaction of regulatory officials, background levels of the compounds of concern could drive the testing program well beyond the impacted area (if any).

Literature data on background levels of solvents in indoor air are scant, further limited by the high detection limits associated with earlier studies. More recent studies have demonstrated techniques for evaluating background levels and provide some of the only low detection limit data for certain compounds<sup>27</sup>.

#### D. TCE and DCE Indoor Air Action Levels

Indoor air action levels for various VOCs are extremely variable. For example, at the time of writing, the TCE action level associated with a one in one million risk of cancer is 0.009 ug/m<sup>3</sup> in the State of New York benchmark air concentration table<sup>28</sup>, 0.016 ug/m<sup>3</sup> in the EPA

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<sup>25</sup> Kurtz, J. and D. Folkes (2002), *Background Concentrations of Selected Indoor Chlorinated Hydrocarbons in Residential Indoor Air*, 9<sup>th</sup> Int. Conf. on Indoor Air, Monterey, CA.

<sup>26</sup> Foster, S., J. Kurtz and A. Woodland (2002), *Background Indoor Air Risks at Selected Residences in Denver, Colorado*, 9<sup>th</sup> Int. Conf. on Indoor Air, Monterey, CA.

<sup>27</sup> Kurtz, J. and D. Folkes (2002), *Background Concentrations of Selected Indoor Chlorinated Hydrocarbons in Residential Indoor Air*, 9<sup>th</sup> Int. Conf. on Indoor Air, Monterey, CA.

<sup>28</sup> State of New York Department of Health Benchmark Air Concentrations, Bureau of Toxic Substance Assessment, May 10, 2002 version.

Region III risk-based concentration table<sup>29</sup>, and 1.4 ug/m<sup>3</sup> in Colorado residential risk concentration tables. These concentrations vary by over three orders of magnitude.

The wide disparity in the TCE screening or action levels is primarily due to different inhalation cancer slope factors used in their derivation. At the time of writing, no inhalation cancer slope factor is provided for TCE on the EPA Integrated Risk Information System (IRIS)<sup>30</sup>. Colorado bases its risk concentrations on the old cancer slope factor, while New York and EPA Region III base their values on a proposed cancer slope factor. The difference between the New York and EPA Region III concentrations is caused by different exposure assumptions, such as the exposure duration (e.g., 70 versus 30 years).

EPA is expected to publish final toxicity criteria for TCE in IRIS in the near future. This will clearly have a significant impact on risk assessments and action levels at vapor intrusion sites. If selected, the lower proposed slope factors would cause TCE to be the principal risk driver at most vapor intrusion sites with significant concentrations of this compound.

At the time of writing, vapor intrusion at the Colorado sites are driven by 1,1-dichloroethene (1,1-DCE), a degradation product of 1,1,1-TCA and TCE with an extremely low action level of 0.49 ug/m<sup>3</sup><sup>31</sup>. In August 2002, EPA withdrew the cancer slope factor for 1,1-DCE from the IRIS database, and published a non-carcinogenic Reference Concentration (RfC) of 200 ug/m<sup>3</sup>. Colorado is currently evaluating the new 1,1-DCE toxicity criteria but continues to use the old cancer slope factor pending any decisions.

Clearly, it is important for responsible parties to be aware of both current and potential future vapor intrusion action levels that might drive evaluation and remediation decisions at their sites.

#### E. Risk Level

Many VOCs are considered to be possible or probable carcinogens, with action levels based on excess cancer risk. At EPA lead sites, action levels based on a 10<sup>-4</sup> risk level have been approved<sup>32</sup>, whereas Colorado bases its requirements for vapor mitigation on a 10<sup>-5</sup> risk level, with an ultimate goal of 10<sup>-6</sup>. The proposed OSWER vapor intrusion guidance presents screening levels based on all three risk levels (10<sup>-4</sup>, 10<sup>-5</sup>, 10<sup>-6</sup>), leaving the final selection of appropriate risk level to the lead agency.

### V. MANAGING LIABILITIES

The new regulatory focus on vapor intrusion is very new and may have yet to impact all areas of the country – but it clearly will impact all areas sooner or later and, based on the number

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<sup>29</sup> [www.epa.gov/reg3hwmd/risk/index.htm](http://www.epa.gov/reg3hwmd/risk/index.htm), October 9, 2002 version.

<sup>30</sup> [www.epa.gov/iris](http://www.epa.gov/iris)

<sup>31</sup> Interim action level for vapor mitigation, based on a 10<sup>-5</sup> excess cancer risk. The long term risk goal is 10<sup>-6</sup>.

<sup>32</sup> Hamilton Sundstrand site in Region VIII

of calls the authors receive from agencies, industry, and attorneys across the U.S. and Canada, the momentum is growing rapidly. There are many actions that site owners and operators can and should take now to limit the risks and liabilities associated with vapor intrusion.

#### A. ASSESSING AND PRIORITIZING SITES

To manage and control risks associated with potential vapor intrusion concerns at a site, you have to know what those risks are. Any site owner or operator where groundwater has been impacted by VOCs should assess the potential for vapor intrusion impacts, using competent technical experts who are familiar with state-of-the-art techniques and issues. Ideally, this evaluation would be conducted before being required by a regulatory agency. Owners of multiple sites and facilities may want to prioritize sites first, using simple screening criteria, and then focus on the most critical locations.

Once potential risks, if any, have been identified, site owners and operators are better equipped to take pre-emptive actions to reduce risk. This may include accelerated cleanup or source control of plumes that were previously thought to be candidates for more passive remedies.

If screening level evaluations indicate the potential for vapor intrusion, more detailed evaluations using site-specific data should be conducted to reduce the conservatism inherent in most screening criteria. Depending on site conditions, additional groundwater, soil, and/or soil vapor data may eliminate the need for indoor air testing.

#### B. DUE DILIGENCE

An evaluation of vapor intrusion potential should be a part of any due diligence process associated with mergers or acquisitions of industrial properties. The potential costs and liabilities associated with vapor intrusion impacts could be orders of magnitude higher than those due to traditional groundwater contamination issues.

#### C. CONTROLLING THE PROCESS

The science of vapor intrusion is still in its infancy and regulators are still being trained in the application of the proposed OSWER guidance. Very little information is available in the technical literature. As a result, there is significant potential for misconceptions and misunderstandings that could lead the regulatory process astray. To prevent overly conservative and burdensome requirements, responsible parties must ensure that they remain in control of the process from the beginning.

To be in control, responsible parties, their attorneys, and consultants, must understand the vapor intrusion pathway, the state-of-the-art technology required to evaluate the pathway, the status of controversial issues, and how these might impact decisions at the site in question. By being proactive, responsible parties can identify risks in advance, reduce these risks through pre-emptive actions, and propose reasonable scopes of work to regulatory agencies, if required.

## Biographies

### David J. Folkes, P.E.

Mr. Folkes is President of EnviroGroup Limited and the Project Director for the largest known chlorinated solvent vapor intrusion site in North America, including mitigation of over 360 buildings with elevated concentrations of solvent vapors, and indoor air testing of over 700 buildings. He has also been involved in vapor intrusion cases in Texas, Utah, and Ontario, Canada. An invited speaker at EPA's regional training seminars in 2002-2003 and the RCRA National Meetings in 2000 and 2002, he has provided federal and state regulators with practical advice on vapor intrusion testing, mitigation, and community interaction issues. Areas of active research include background or indoor sources of solvents in air, the correlation between groundwater and indoor air concentrations of VOCs, seasonal effects on vapor intrusion, and the efficacy of mitigation techniques.

With over 25 years experience in environmental consulting, Mr. Folkes has investigated and remediated a wide variety of industrial and natural resource sites with organic, petroleum, and metals impacts. He has published and presented papers on numerous environmental topics, including groundwater and vapor intrusion remediation, and served as an expert witness in both state and federal court.

### Paul S. Arell, P.E., DEE

Mr. Arell is a Senior Project Manager with EnviroGroup Limited and a Diplomate of the American Academy of Environmental Engineers, with over 30 years of experience ranging from water pollution control, to Superfund, to hazardous waste corrective action under RCRA. Most recently, Mr. Arell managed the RCRA Corrective Action Program at the EPA, Region VIII for six years. In that capacity, he implemented federal corrective action at a number of facilities in Colorado. Two of these high profile facilities had vapor intrusion aspects that required state-of-the-art indoor air testing and remediation. Mr. Arell also organized and led a state/Federal workgroup to coordinate cleanup of complex petroleum refineries. He accelerated progress on corrective action projects, reducing time and money spent in completing cleanup actions.