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Standard Guide for Evaluating Potential Hazard in Buildings as a Result of Methane in the Vadose Zone[1]

This standard is issued under the fixed designation E2993; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides a consistent basis for assessing methane in the vadose zone, evaluating hazard and risk, determining the appropriate response, and identifying the urgency of the response.

1.2 *Purpose*—This guide covers techniques for evaluating potential hazards associated with methane present in the vadose zone beneath or near existing or proposed buildings or other structures (for example, potential fires or explosions within the buildings or structures), when such hazards are suspected to be present based on due diligence or other site evaluations (see 6.1.1). Buildings in this context include normal below grade utilities associated with a building.

1.3 *Objectives*—This guide: *(1)* provides a practical and reasonable industry standard for evaluating, prioritizing, and addressing potential methane hazards based on mass flow and *(2)* provides a tool for screening out low-risk sites.

1.4 This guide offers a set of instructions for performing one or more specific operations. This guide cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This guide is not intended to represent or replace the standard of care by which the adequacy of a given professional service should be judged, nor should this guide be applied without consideration of a project's many unique aspects. The word "Standard" in the title means only that the guide has been approved through the ASTM International consensus process.

1.5 Not addressed by this guide are:

1.5.1 Requirements or guidance or both with respect to methane sampling or evaluation in federal, state, or local regulations. Users are cautioned that federal, state, and local guidance may impose specific requirements that differ from those of this guide;

1.5.2 Safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use;

1.5.3 Emergency response situations such as sudden ruptures of gas lines or pipelines;

1.5.4 Methane entry into an enclosure from other than vadose zone soils (for example, methane evolved from well water brought into an enclosure; methane generated directly within the enclosure; groundwater intrusion, methane from leaking natural gas lines or appliances within the enclosure, direct migration into buildings from mine entries, etc.);

1.5.5 Methane entry into an enclosure situated atop or immediately adjacent to a municipal solid waste (MSW) landfill or a Construction and Demolition (C&D) landfill;

1.5.6 Methane from oil & gas reservoirs, injection wells, or other sources potentially under high pressures relative to typical vadose zone pressures;

1.5.7 Methane risk during construction activities, work in trenches, and confined space work (which are all best addressed via real-time monitoring);

1.5.8 Potential hazards from other gases and vapors that may also be present in the subsurface such as hydrogen sulfide, carbon dioxide, and/or volatile organic compounds (VOCs);

1.5.9 Anoxic conditions in enclosed spaces;

1.5.10 The forensic determination of methane source; or

1.5.11 Potential consequences of fires or explosions in enclosed spaces or other issues related to safety engineering design of structures or systems to address fires or explosions.

1.6 *Units*—The values stated in SI units are to be regarded as the standard.

1.6.1 *Exception*—Values in inch/pound units are provided for reference.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.02 on Real Estate Assessment and Management.

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Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D1946 Practice for Analysis of Reformed Gas by Gas Chromatography

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D6725 Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers

D7663 Practice for Active Soil Gas Sampling in the Vadose Zone for Vapor Intrusion Evaluations

E2600 Guide for Vapor Encroachment Screening on Property Involved in Real Estate Transactions

F1815 Test Methods for Saturated Hydraulic Conductivity, Water Retention, Porosity, and Bulk Density of Athletic Field Rootzones

2.2 *Other Standards:*

British Standards Institution (BSI), Guidance on Investigations for Ground Gases, Permanent Gases, and Volatile Organic Compounds (VOCs). BS8576. 2013 [3]

British Standards Institution (BSI), Code of Practice for the Design of Protective Measures for Methane and Carbon Dioxide Ground Gases for New Buildings. BS 8485:2015+A1:2019[3]

California DTSC, Evaluation of Biogenic Methane for Constructed Fills and Dairies Sites, March 28, 2012

CL:AIRE Ground Gas Monitoring and “Worst Case” Conditions. August 2018

County of Los Angeles Building Code, Volume 1, Title 26, Section 110 Methane[4]

ITRC Document VI-1 Vapor Intrusion Pathway: A Practical Guideline[5]

ITRC Document PVI-1 Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management[6]

EPA 530-R-10-003 Conceptual Model Scenarios for the Vapor Intrusion Pathway

New South Wales (NSW) EPA. Assessment and Management of Hazardous Ground Gases. May 2020.

29 CFR 1910.146 Permit-Required Confined Spaces[7]

3. Terminology

3.1 *Definitions:*

3.1.1 This section provides definitions and descriptions of terms used in or related to this guide. An acronym list is also included. The terms are an integral part of this guide and are critical to an understanding of the guide and its use.

3.1.2 *advection, n*—transport of molecules along with the flow of a greater medium as occurs because of differential pressures.

3.1.3 *ambient air, n*—any unconfined portion of the atmosphere; open air.

3.1.4 *barometric lag, n*—time difference between changes in total atmospheric pressure (barometric pressure) and subsequent changes in total gas pressure measured at a specific point in the subsurface.

3.1.4.1 *Discussion*—Atmospheric pressure variations include routine diurnal highs and lows as well as changes associated with exceptional meteorological conditions (weather fronts). The time lag means that differential pressure between the surface and the subsurface point may be out of phase and may reverse (± relative to zero) with resulting reversals in soil gas flow direction over time between the shallow subsurface and the surface.

3.1.5 *barometric pumping, n*—variation in the ambient atmospheric pressure that causes motion of vapors in, or into, porous and fractured earth materials.

3.1.6 *biogas, n*—mixture of methane and carbon dioxide produced by the microbial decomposition of organic wastes, also known as microbial gas.

3.1.6.1 *Discussion*— For the purposes of this standard, biogas may arise from any organic material not specifically excluded in 1.5. The sources addressed include plant material, soil organic carbon, and petroleum hydrocarbons from past releases.

3.1.7 *biogenic, adv*—resulting from the activity of living organisms.

3.1.8 *contaminant, n*—substance not normally found in an environment at the observed concentration.

3.1.9 *continuous monitoring, n*—measurements of selected parameters performed at a frequency sufficient to define critical trends, identify changes of interest, and allow for relationships with other attributes in a predictive capacity.

3.1.10 *dead volume, n*—total air-filled internal volume of the sampling system.

3.1.11 *differential pressure, n*—relative difference in pressure between two measurement points (ΔP).

3.1.11.1 *Discussion*—ΔP measurements are typically the differences between pressure at some depth in the vadose zone and pressure above ground at the same location (indoors or

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

[4] Available from dpw.lacounty.gov.

[5] Available from the Interstate Technology & Regulatory Council, http://www.itrcweb.org/Documents/VI-1.pdf.

[6] Available from the Interstate Technology & Regulatory Council, http://www.itrcweb.org/PetroleumVI-Guidance/

[7] Available from Occupational Safety and Health Administration (OSHA), 200 Constitution Ave., Washington, DC 20210, http://www.osha.gov.

outdoors), but also could refer to the difference in pressure between two subsurface locations. A ΔP measurement represents a pressure gradient between the two locations.

3.1.12 *diffusion, n*—gas transport mechanism in which molecules move along a concentration gradient from areas of higher concentration toward areas of lower concentration; relatively slow form of gas transport.

3.1.13 *effective porosity, n*—amount of interconnected void space (within intergranular pores, fractures, openings, and the like) available for fluid movement: generally less than total porosity.

3.1.14 *flammable range, n*—concentration range in air in which a flammable substance can produce a fire or explosion when an ignition source is present.

3.1.14.1 *Discussion*—The flammable range extends from the lower flammable limit (LFL) to the upper flammable limit (UFL). See Appendix X1, X1.6.

3.1.15 *fracture, n*—break in the mechanical continuity of a body of rock or soil caused by stress exceeding the strength of the rock or soil and includes joints and faults.

3.1.16 *groundwater, n*—part of the subsurface water that is in the saturated zone.

3.1.17 *hazard, n*—source of potential harm from current or future methane exposures.

3.1.18 *indoor air, n*—the mixture of gases within the habitable spaces of a building

3.1.19 *microbial, adv*—pertaining to or emanating from a microbe.

3.1.19.1 *Discussion*—The preferred term for nonthermogenic, nonpetrogenic methane such as from anaerobic activity in shallow soils or sanitary landfills is "microbial."

3.1.20 *moisture content, n*—amount of water lost from a soil upon drying to a constant weight expressed as the weight per unit weight of dry soil or as the volume of water per unit bulk volume of the soil.

3.1.21 *perched aquifer, n*—lens of saturated soil above the main water table that forms on top of an isolated geologic layer of low permeability.

3.1.22 *permeability, n*—ease with which a porous medium can transmit a fluid under a potential gradient.

3.1.23 *preferential pathway, n*—migration route for chemicals of concern that has less constraint on gas transport than the surrounding soil.

3.1.23.1 *Discussion*—Preferential pathways may be natural (for example, vertically fractured bedrock where the fractures are interconnected) or man-made (for example, utility conduits, sewers, and dry wells).

3.1.24 *pressure-driven flow, n*—gas transport mechanism that occurs along pressure gradients resulting from introduction of gas into the soil matrix.

3.1.24.1 *Discussion*—The flow of gas is from the region of high pressure to regions of lower pressure and continues until the gas pressure is equal or the flowpath is blocked. With advection, molecules are transported along with the flow of a greater medium. With pressure-driven flow, the introduced gas is the medium.

3.1.24.2 *Discussion*—In the vadose zone, elevated pressures in a given volume of soil can occur as a result of biogas generation at that location. Therefore, whether or not a given site has active biogas generation is an important consideration in evaluating methane hazard.

3.1.25 *porosity, n*—volume fraction of a rock or unconsolidated sediment not occupied by solid material but usually occupied by liquids, vapor, and/or air.

3.1.25.1 *Discussion*—Porosity is the void volume of soil divided by the total volume of soil.

3.1.26 *probe, n*—device designed to investigate and collect information from a remote location.

3.1.26.1 *Discussion*—As used in this guide, a point or methane test well used to collect information from within the vadose zone or subslab space of a building.

3.1.27 *purge volume, n*—amount of air removed from the sampling system before the start of sample collection.

3.1.27.1 *Discussion*—This is usually referred to in terms of number of dead volumes of probe (test well) casing or test well plus granular backfill total volume.

3.1.28 *repressurization, n*—unpressurized soil vapors can be pressurized by phenomena such as rapidly rising groundwater.

3.1.29 *risk, n*—probability that something will cause injury or harm.

3.1.30 *saturated zone, n*—zone in which all of the voids in the rock or soil are filled with water at a pressure that is greater than atmospheric.

3.1.30.1 *Discussion*—The water table is the top of the saturated zone in an unconfined aquifer.

3.1.31 *soil gas, n*—vadose zone atmosphere; soil gas is the air existing in void spaces in the soil between the groundwater table and the ground surface.

3.1.32 *soil moisture, n*—water contained in the pore spaces in the vadose zone.

3.1.33 *subslab vapor sampling, v*—collection of vapor from the zone just beneath the lowest floor slab of a building or below paving or soil cap.

3.1.34 *thermogenic, adj*—methane that is generated at depth under elevated pressure and temperatures during and following the formation of petroleum (for example, in oil fields).

3.1.35 *tracer, n*—material that can be easily identified and determined even at very low concentrations and may be added to other substances to enable their movements to be followed or their presence to be detected.

3.1.36 *tracer gas, n*—gas used with a detection device to determine the rate of air interchange within a space or zone or between spaces or zones.

3.1.37 *vadose zone, n*—hydrogeological region extending from the soil surface to the top of the principal water table.

3.1.37.1 *Discussion*—Perched groundwater may exist within this zone.

3.1.38 *vapor intrusion, n*—migration of a volatile chemical(s) from subsurface soil or water into an overlying or nearby building or other enclosed space.

3.1.39 *volatile organic compound, VOC, n*—an organic compound with a saturation vapor pressure greater than 10^{-2} kPa at 25°C (Terminology D1356-14).

3.1.40 *water table, n*—top of the saturated zone in an unconfined aquifer.

3.2 *Acronyms and Abbreviations:*

3.2.1 *ACH*—air changes per hour

3.2.2 *CSM*—conceptual site model

3.2.3 *FID*—flame ionization detector

3.2.4 *HVAC*—heating, ventilation, and air conditioning

3.2.5 *In.* H_2O—inches of water, a measure of pressure exerted by a column of water 1 in. (2.54 cm) in height; 1 in. H_2O equals approximately 250 Pa

3.2.6 *LEL*—lower explosive limit (same as lower flammable limit)

3.2.7 *Pa*—Pascal, a measure of pressure

3.2.8 *ppmv*—part per million on a volume basis

3.2.9 *psi*—pounds per square inch

3.2.10 *QA/QC*—quality assurance/quality control

3.2.11 *UEL*—upper explosive limit (same as upper flammable limit)

3.2.12 *USEPA*—U.S. Environmental Protection Agency

3.2.13 *VOC*—volatile organic compound

3.2.14 *v/v*—by volume, as in percent by volume (% v/v)

4. Summary of Guide

4.1 This guide describes site screening, testing, data analysis, evaluation, and selection of mitigation alternatives.

4.2 *Three-Tiered Approach*—This guide provides an approach for assessing and interpreting site methane, evaluating hazard and risk, determining the appropriate response, and identifying the urgency of the response. The approach is based on understanding the potential mass flow at a site and not relying solely upon concentration measurements. A three-tiered approach is given that uses a decision matrix based on methane concentrations in the vadose zone and other factors such as indoor air concentrations, differential pressure measurements, and estimates of the volume of methane within soil gas near a building to determine the potential hazard. Alternatively, rather than using these indirect measures of gas transport potential, gas flowrates can be measured directly (see Appendix X4). For highly permeable soils or fill materials, direct measurements of gas flowrates will provide better, more conservative assessments. The *first tier* consists of a site evaluation that can typically be done using existing, available information. This information is compiled, reviewed, and used to develop a conceptual site model (CSM). The CSM should describe and summarize the source of any methane that is present, vadose zone conditions (for example, depth to groundwater and soil type), size of impacted area, design and use of any existing buildings, exposure scenario, and other relevant lines of evidence for a given site. A decision matrix is applied to get an initial prediction of hazard. For sites in which potentially significant data gaps are identified during the Tier 1 review, the *second tier* consists of a refined site evaluation. Additional field work is performed to address the data gaps. The results are compared with the CSM and the CSM revised, as necessary. The decision matrix is again applied to the new, expanded data set to get an updated prediction of hazard. If it is determined that more data are needed, the *third tier* consists of a special case evaluation. For all three tiers, the path forward at any point should respect applicable regulatory guidance and consider risk management principles, technical feasibility, and community concerns.

4.2.1 The evaluation process is typically implemented in a tiered approach involving increasingly sophisticated levels of data collection, analysis, and evaluation. Users may choose to proceed directly to the most sophisticated tier, to pre-emptive mitigation, or to routine monitoring based on site-specific circumstances. It is good practice to seal utility openings and plug potential gas entry points for any site with potential for methane.

4.2.2 For some sites, a limited number of samples may not be sufficient to address potential hazard because there are *(1)* a large volume (for example, >100 m^3) of methane gas and/or significant potential methane source(s) at or nearby the site (for example, a large mass (for example, >500 m^3) of buried organic matter such as plants, wood, etc.) *(2)* high-permeability preferential pathways present that may result in higher than typical rates of vapor transport (for example, gravel trench for utility lines), *(3)* relatively high permeability soils (for example, sand or gravel) with insufficient moisture to support methanotrophic bacteria, or *(4)* changes in groundwater elevation over short time periods, which can create pressure gradients in the vadose zone. For such sites, presumptive mitigation or Tier 3 evaluation (for example, continuous or regular monitoring) should be considered.

4.3 *Site Categorization*—This guide is designed to promote rapid site characterization so that low-risk sites can be identified and efficiently removed from further evaluation. Conversely, high-risk sites can be identified and appropriate follow-up actions taken promptly. This guide focuses on Tier 1 and 2 evaluations. Special case evaluations (Tier 3) are generally outside the scope of this guide, but applicable tools and considerations are described for information purposes.

5. Significance and Use

5.1 Several different factors should be taken into consideration when evaluating methane hazard, rather than, for example, use of a single concentration-based screening level as a de-facto hazard assessment level. Key variables are identified and briefly discussed in this section. Legal background information is provided in Appendix X3. The Bibliography includes references where more detailed information can be found on the effect of various parameters on gas concentrations.

5.2 *Application*—This guide is intended for use by those undertaking an assessment of hazards to people and property as a result of subsurface methane suspected to be present based on due diligence or other site evaluations (see 6.1.1).

5.2.1 This guide addresses shallow methane, including its presence in the vadose zone; at residential, commercial, and industrial sites with existing construction; or where development is proposed.

5.3 This guide provides a consistent, streamlined process for deciding on action and the urgency of action for the identified hazard. Advantages include:

5.3.1 Decisions are based on reducing the actual risk of adverse impacts to people and property.

5.3.2 Assessment is based on collecting only the information that is necessary to evaluate hazard.

5.3.3 Available resources are focused on those sites and conditions that pose the greatest risk to people and property at any time.

5.3.4 Response actions are chosen based on the existence of a hazard and are designed to mitigate the hazard and reduce risk to an acceptable level.

5.3.5 The urgency of initial response to an identified hazard is commensurate with its potential adverse impact to people and property.

5.4 *Limitations*—This guide does not address potential hazards from other gases and vapors that may also be present in the subsurface such as hydrogen sulfide, carbon dioxide, and/or volatile organic compounds (VOCs) that may co-occur with methane. If the presence of hydrogen sulfide or other potentially toxic gases is suspected, the analytical plan should be modified accordingly.

5.4.1 The data produced using this guide should be representative of the soil gas concentrations in the geological materials in the immediate vicinity of the sample probe or well at the time of sample collection (that is, they represent point-in-time and point-in-space measurements). The degree to which these data are representative of any larger areas or different times depends on numerous site-specific factors. The smaller the data set being used for hazard evaluation, the more important it is to bias measurements towards worst-case conditions.

5.5 *Variables and Site-Specific Factors that May Influence Data Evaluation:*

5.5.1 *Gas Transport Mechanisms*—Methane migration in soil gas results from pressure-driven flow, advection and diffusion. Advective transport (for example, biogas within a soil gas matrix) and pressure-driven flow (for example, pure or nearly pure biogas) has been associated with methane incidents (for example, fires or explosions), whereas no examples are known of methane incidents resulting from diffusive transport alone. Therefore, diffusion is not considered a key transport mechanism when evaluating methane hazard.

5.5.1.1 The potential for significant rates of soil gas transport can often be recognized by relatively high differential pressures (for example, >500 Pa [2 in. H_2O]), high concentrations of leaked or generated gas, and concurrent displacement of atmospheric gases (nitrogen, argon) from the porous soil matrix. Alternatively, gas flowrates can be measured directly (see Appendix X4).

5.5.2 *Effect of Gas Transport Mechanisms:*

5.5.2.1 *Near-Surface Advection Effects*—Within buildings, across building foundations, and in the immediate subsurface vicinity of building foundations, advective flow may be driven by temperature differences, the on-off cycling of building ventilation systems, the interaction of wind and buildings, and/or changes in barometric pressure. These mechanisms can pump air back and forth between the soil and the interior of structures. The effects may be significant in evaluation of VOC or radon migration between buildings and the subsurface, but generally are relatively minor factors in evaluation of methane migration and hazard unless the source of methane is in very shallow soils.

5.5.2.2 *Source Zone Flow Effects*—Biogenic (microbial) gas generation (methanogenesis) results in a net increase in molar gas volume near the generation source. The resulting increased gas pressure causes gas flow away from the source zone. This gas flow typically originates near sources of buried organic matter. Pressure-driven flow can also result from pressurized subsurface gas sources including leaks from natural gas distribution systems, subsurface gas storage, or seeps from natural gas reservoirs. The evaluation of pressurized sources of gas themselves (for example, pipelines, reservoirs, or subsurface storage) is outside the scope of this guide (see 1.5.3 – 1.5.6).

5.5.2.3 Subsurface soil gas pressure change can also occur in other instances, such as with a rapidly rising or falling water table in a partially confined aquifer or barometric pumping of fractured bedrock or very coarse gravel. This effect may occur in conjunction with advection of either dilute or high-concentration soil gases and may be irregular or intermittent. Induced pressure driven flow in response to diurnal barometric pressure changes is both upward and downward and there is no net upward pressure gradient. The CSM should consider the potential for induced pressure-driven flow (which is sometimes referred to as repressurization).

(1) Significant gas flow due to barometric pressure fluctuations may occur for nearby subsurface gas void volumes (nominal gas volumes of 4000 m^3 or greater) in confined coarse sand or gravel connected to a building or enclosure

(2) Significant gas flow due to water table changes may occur for changes of 10 cm/day or greater in confined coarse sand or gravel connected to a building or enclosure.

5.5.3 *Effect of Land Use*—Combustible soil gas is a concern mostly for sites with confined habitable space because of the safety risk. Combustible soil gas can also be a concern at sites with other types of confined spaces, such as manholes or buried vaults where a source of ignition may be present. Proximity or entry to such spaces may require consideration of hazards associated with methane.

5.5.4 *Pathways*—Pathways into buildings from the soil can include cracks in slabs, unsealed space around utility conduit penetrations, the annular space inside of dry utilities (electrical, communications), elevator pits (particularly those with piston wells), basement sumps, sewer lines with dry water traps, and other avenues.

5.5.5 *Effect of Hardscape and Softscape*—Any capping of the ground surface can impede the natural venting of soil gas with concrete being generally less permeable than asphalt. Hardscape and well irrigated softscape both present barrier conditions. Existing hardscape/softscape conditions should be noted during soil gas investigations. Proposed hardscape/softscape conditions should be considered when formulating alternatives for action at sites where methane hazard is to be mitigated. The potential for future hardscape/softscape conditions also should be taken into account when evaluating the representativeness of methane and pressure data.

5.5.6 *Effect of Soil Physical Properties*—The diffusion of gas through soil is controlled by the air-filled porosity of the soil, whereas the advection and pressure-driven flow of gas through soil is controlled by the permeability of the soil. Two soils can have similar porosities but different permeabilities and vice-versa. The effective porosity of a soil may be different than the total porosity depending on whether the soil pores are connected or not. For methane transport, advective and pressure-driven flow is of much more concern than diffusive flow, so permeability is a more important variable than porosity. Large spaces such as fractures in fine-grained soils can impart a high permeability to materials that would otherwise have a low permeability. Soil moisture can reduce the air-filled porosity of soil and the gas permeability thereby reducing both diffusive and advective flow of soil gas.

5.5.7 *Effect of Environmental Variables*—A number of environmental variables can affect the readings taken in the field and can be important in interpreting the readings once taken. The effect of environmental variables tends to be greatest for very shallow measurements in the vadose zone and typically is of limited importance at depths of 1.5 m and greater.

5.5.8 *Atmospheric Pressures and Barometric Lag*—A falling barometer may leave soil gas under pressure as compared with building interiors enabling increased soil gas flux out of the soil and into structures. The interpretation of barometric lag data should take into account the type of soil. Barometric lag is most pronounced in tight (clayey) soils in which the flow of gases is retarded; barometric lag is least pronounced in granular (sandy) soils that provide the greatest permeability for the flow of gas. The potential for pressure-driven gas transport through soil is significant only for permeable soil pathways (that is, air-filled coarse sands and gravels).

5.5.9 *Precipitation*—Normal outdoor soil gas venting (that is, emissions at soil surface) is impeded when moisture fills the surface soil pore space. Infiltrating rainwater may displace soil gas and cause it to vent into structures. Increases in soil moisture following rain or other precipitation events can lead to enhanced rates of biogas generation, which may be evaluated through repeated measurements.

5.5.10 *Effect of Sampling Procedures*—Sampling probes (test wells) typically are designed to identify soil gas pressures and maximum soil gas concentrations at the point of monitoring. The sequence of steps (for example, purging, pressure and concentration readings, and so forth) can affect the results. For differential pressure measurements, gages capable of measuring 500 Pa (2 in. H_2O) may be used. Ideally, the gage or gages should be capable of measurements over a range of pressures (for example, 0 to 1,250 Pa (0 to 5 in. H_2O)) and have a resolution of at least 25 Pa (0.1 in. H_2O). See the Bibliography for references on equipment for concentration and differential pressure measurements. Initial readings of pressure should be taken before any gas readings, as purging can reduce any existing pressure differential and steady-state conditions may not be reestablished for some time afterwards. Soil gas pressures and soil gas concentrations should also be measured after purging. The recovery, or change of pressure with time, may also be of interest. Gas pressure readings taken in groundwater monitoring wells may not be representative of vadose zone pressures.

5.6 *Applicability of Results*—Instantaneous data from monitoring probes represent conditions at a point in space and time. Worst-case, short-term impacts are of interest in a methane evaluation because of the acute risk posed by methane. Single-sampling events in which data are collected from a number of points at different locations may be sufficient if there is a robust CSM (that is, accounting for worst-case conditions) and the site is well understood. If site results are inconsistent with the CSM, additional data may be needed to address uncertainties and increase the statistical reliability and confidence in the results.

6. Approach to Methane Hazard Evaluation

6.1 *Decision Framework:*

6.1.1 Investigations may be triggered by site-specific findings (for example, observations of bubbling at ground surface or in water wells; measurement of methane in soil gas; odors; or, in extreme cases, fire or explosion or both) or may result from planned studies (for example, methane evaluations pursuant to property transfer, property refinance, or during the application process for a building permit). Investigation of methane in soil may also follow detection during other investigations, such as in confined space screening (29 CFR 1910.146) or environmental investigation of chemical-impacted soils and groundwater. The general process is shown in Fig. 1. The volume of gas that is important will depend on the size of the building footprint. In general, the greater the spatial extent of soil gas with elevated methane, the greater the potential for vapor intrusion of methane to be an issue. A single, isolated hot spot of 5 to 30 % methane is unlikely to result in an indoor air issue with the hazard dependent on the volume of the hot spot relative to the volume of the indoor space and the lateral distance from the hot spot to the building.

6.1.2 Decision making uses a matrix of soil gas and indoor air values to address both current risk and potential future risk (see Table 1). The matrix is a risk management approach that uses conservative screening values for methane concentration and differential pressure to rank site hazard. The available volume of soil gas containing elevated levels of methane also is a consideration. The volume of gas at a given methane concentration and differential pressure generally should be assumed to be sufficient to pose a potential issue unless the contrary can be demonstrated via the CSM and/or field measurements. It is important to recognize that the values are guidelines and not absolute thresholds. Concentrations and pressure need to be considered in terms of the CSM. The decision matrix shown in Table 1 is a suggested starting point and should be adjusted as appropriate for site-specific conditions. The 500 Pa (2 in. H_2O) criterion for ΔP is based on measurements in the vadose zone at a depth or interval of 1.5 m

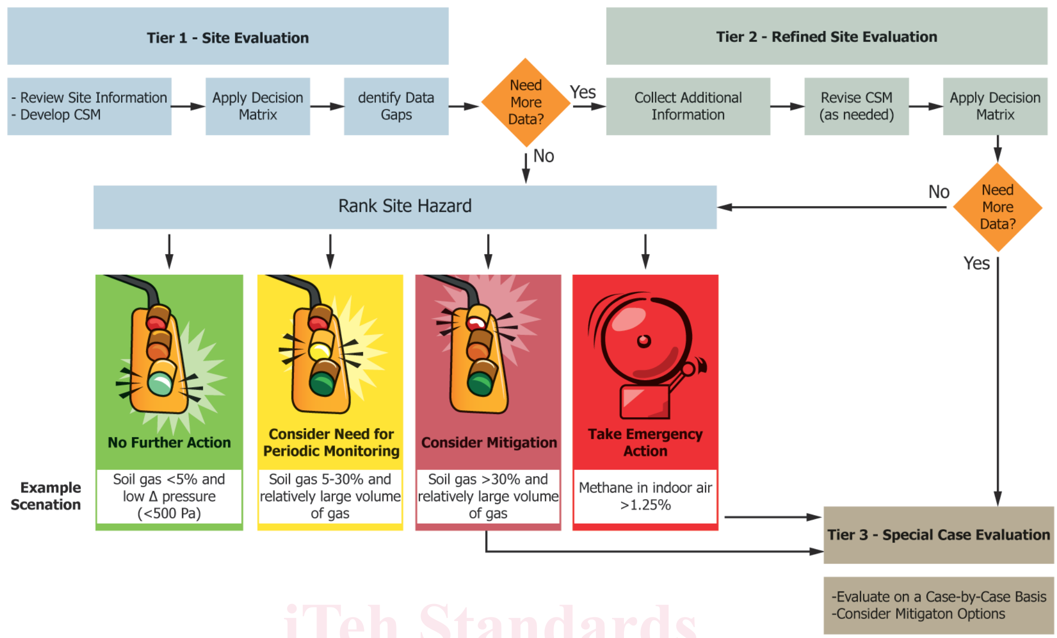

FIG. 1 Tiered Evaluation Process

TABLE 1 Suggested Default Decision Matrix for Methane in Soil Gas and Indoor Air

NOTE 1—Table based on Eklund, 2011 (**1**) and Sepich, 2008 (**2**)[D] . See also Appendix X2. Table is intended for sites with existing buildings. To address future development, no further action is recommended if the shallow soil gas concentration of methane is <30% and ΔP <500 Pa. The potential for conditions to change in the future should be considered. Sites that cannot be screened out merit further evaluation (see Section 6).

NOTE 2—If the combined soil gas concentrations of methane and carbon dioxide are ≥90%, biogas generation likely is recent or on-going and mitigation should be considered.

NOTE 3—Soil gas outside the building footprint but within a radius of 60 m (200 ft) of the building may be of interest. The total mass of methane present should be considered (that is, concentration × volume).

Shallow Soil Gas Conc.[A]	Indoor Air Concentration			
	No Measurements Available	<0.01% (that is <100 ppm)	0.01 to <1.25%	>1.25%
<1.25% to 5%	No further action	No further action	Identify indoor sources[B]	Immediately notify authorities, recommend owner/operator evacuate building
>5% to 30%[C,E]	No further action unless ΔP >500 Pa[B]	Mitigate gas entry points[B]	Mitigate gas entry points[B]	Immediately notify authorities, recommend owner/operator evacuate building
>30%[C,E]	Collect indoor air data	Evaluate on case-by-case basis	Evaluate on case-by-case basis	Immediately notify authorities, recommend owner/operator evacuate building

[A] Maximum methane soil gas value (% CH4) for area of building footprint. Shallow soil gas refers to soil gas in the vadose zone within the top 10 m (33 ft) of soil below ground surface but at least 1 m from the building envelope. If methane exceeds 5 % within 1 m of the building, the default decision matrix is not applicable.
[B] Landowner or building owner/manager should identify indoor sources and reduce/control emissions. If no sources are found, additional subsurface characterization and continued indoor air monitoring should be considered. ΔP refers to pressure gradients in the subsurface at a depth or interval of 1.5 m. For sandy soils, gravel, or other highly permeable matrices, direct measurement of methane flow may be appropriate (see Appendix X4).
[C] The potential for pressure gradients to occur in the future at a given site should be considered.
[D] The boldface numbers in parentheses refer to a list of references at the end of this standard.
[E] Potential points of gas entry to the building should be identified and plugged or sealed. If P>500 Pa, further mitigation should be considered.

(for example, difference between pressure measurements 1.5 m below ground surface and ambient air). For measurements at 1.5 m or greater, temporal variability is typically not significant. Measurements at shallower depths (for example, sub-slab) also may be useful, but recognize that there is gr eater potential for temporal variability for shallower measurements or measurements at sites with highly permeable matrices.

6.1.3 The screening values for methane concentration are, in most cases, derived from the lower flammable limit for methane in air, that is, 5 %, since methane hazard is related to flammability rather than toxicity. Concentration, pressure, and volume should be taken into account. Physical and toxicological characteristics of methane are summarized in Appendix X1. Additional discussion of the screening values is provided in Appendix X2. Note that for soil gas, methane concentration alone is insufficient to evaluate potential hazard. Information on pressures and volumes is also essential.

6.1.4 Screening values are location specific. That is, soil gas screening values should be used for comparison with site soil gas results and indoor air/confined space screening values should be compared only with indoor air/confined space results (for example, Table 1).

6.1.5 Volume of methane in the vadose zone for a given site will always be an estimate. The uncertainty in the estimate can be reduced by characterizing the spatial variability. A minimum sampling interval for a developed property is typically one sub-slab measurement per 500 m^2 of building footprint, plus one shallow (for example, 5 ft.) soil vapor sample per 1000 m^2 of property area, and one deeper cluster of soil vapor samples (for example, 5 ft., 10 ft., and 20 ft.) per 2000 m^2 of property area. If readings of 30 % or higher methane are found, it may be helpful to better characterize the relative "hot spot" by collecting additional data to provide a 3-dimensional concentration map in the immediate area.

6.2 *Develop Conceptual Site Model (CSM)*—The user is required to identify the potential primary sources of methane in the subsurface, potential receptor points, and significant likely transport pathways from the primary sources to the receptors. Various vapor intrusion guidance documents describe the development of CSMs (ITRC Document VI-1 and PVI-1 and EPA/OSWER), though not for methane sites. Guidance specific to methane is available (NSW, 2020; BSI, 2013) along with guidance for determining "worst case" conditions (CLAIRE, 2018). The CSM provides a framework for the process of evaluating methane hazard. The CSM summarizes what is known about the site in terms of source, depth to groundwater, geology, data trends, receptors, building design and operation, and so forth. The CSM should consider reasonable worst-case conditions such as falling and low relative barometric pressure conditions or potential soil gas repressurization. The potential for conditions to change in the future should be considered (for example, increase or decrease in impervious cover). The results of any further investigations are compared with the CSM to see whether or not the results are consistent with the expectations derived from the CSM. If the results are found to differ in material ways from these expectations, the CSM will require modification.

6.2.1 *Source*—Methane is produced by two primary mechanisms: thermogenic and microbial (see Appendix X1). Thermogenic methane consists primarily of methane with relatively small amounts of ethane, propane, and higher molecular weight hydrocarbons. Thermogenic or "fossil" methane typically originates from petroleum deposits at depths generally far below the vadose zone. Natural gas is largely thermogenic methane and may occur in coal mines, oil and gas fields, and other geological formations. Thermogenic methane, once produced, is carried in natural gas transmission and distribution lines. Microbial or "biogenic" methane typically is generated at relatively shallow depths by the recent microbial decomposition of organic matter in soil. The "biogas" produced is essentially all methane and carbon dioxide, present at roughly equal percentages. If CH_4 + CO_2 approach 100 %, the gas is said to be "whole" or "undiluted." Microbial methane is a product of decomposition of organic matter in both natural (for example, wetlands and river and lake sediments) and man-made settings (for example, sewer lines, septic systems, and manure piles). A given mass of organic carbon will have a fixed volume of biogas it can potentially generate. For a given organic material, the rate at which this gas generation takes place will largely be a function of the soil moisture. Once all the carbon has been degraded, the site is said to be "gassed out." Note that the organic matter can be degraded without methane generation if other terminal electron receptors (for example, oxygen, nitrate, iron, sulfate) are present or are introduced. Methane can also be effectively "trapped" in the ground and be immobile. Methane adsorbs onto organic material in the ground and desorbs into monitoring wells when they are installed. In fine grained cohesive organic soils such as Alluvium the gas can be adsorbed, trapped in soil pores or dissolved in pore water and does not cause hazardous emissions at the ground surface.

6.2.2 *Transport*—Methane will migrate along pressure gradients from areas where it is present at higher pressures to areas where it is present at lower pressures, or along concentration gradients, also from high to low. The primary mechanism for significant methane migration in subsurface unsaturated soils is pressure-driven flow. Diffusion also occurs but at rates too low to result in unacceptable indoor air concentrations under reasonably likely scenarios. Soils can be a significant sink for methane, with aerobic biodegradation also an important fate and transport consideration.

6.2.3 *Receptors*—Residential, commercial, and industrial buildings, and the individuals therein, are the primary receptors of interest. Buildings typically have roughly 0.5 to 1 air changes per hour (ACH) and a relatively high rate of vapor intrusion is necessary for the indoor atmosphere to approach the lower flammability limit for methane of 5 %. Therefore, portions of the buildings with lower rates of air exchange are of most interest, such as closed cabinets beneath sinks, closets, and stagnant areas of basements. Utility vaults and other small, poorly ventilated subsurface structures may be viewed as receptors or as worst-case indicators of potential conditions in nearby buildings.

6.3 *Use a Tiered Approach*—The evaluation process is typically implemented in a tiered approach involving increasingly sophisticated levels of data collection, analysis, and evaluation. Upon evaluation of each tier, the user reviews the results and recommendations and decides whether more detailed and site-specific analysis is necessary to refine the hazard analysis (see Fig. 1). Fires or explosions caused by intrusion of methane gas from the soil are relatively rare events, so it is assumed that most sites will be "screened out" by this process and result in no further action. (Such events, when they do occur, may be due to large leaks from natural gas transmission or distribution lines, which are outside the scope of this guide. This guide could be used, however, to evaluate residual hazard after the lines have been repaired.)

6.3.1 *Site Evaluation (Tier 1)*—Site information is assembled and evaluated.

6.3.1.1 At a minimum, this should include a desktop review of source (7.1.1 – 7.1.3), pathway (7.1.6 and 7.1.7) and receptor (7.1.8) characteristics, and collection and review of site soil gas measurements.

6.3.1.2 A conceptual site model is developed specific to methane (see 6.2).

6.3.1.3 An initial evaluation of hazard is made using Table 1.

6.3.1.4 The user should select a response action option that best addresses the short-term concerns for the site, if any. Note that the initial response actions listed in Table 1 are not necessarily comprehensive or applicable for all sites.

6.3.1.5 If the initial data evaluation indicates data gaps, collect additional soil gas or other data, as needed, and reevaluate based upon the Fig. 1 and Table 1. For example, in many cases, methane concentration data are available at this stage, but information about carbon dioxide and oxygen concentrations, and differential pressures, may not exist. The amount of organic material in the subsurface that is potentially still subject to microbial degradation also may not be well characterized unless adequate soil-boring logs are available.

6.3.2 *Refined Site Evaluation (Tier 2)*—In many cases, additional site-specific data will be needed to support an evaluation of methane hazard. These additional data needs may include any or all of the following: *(1)* speciating the soil gas including measuring methane, carbon dioxide, higher order hydrocarbons, hydrogen sulfide, oxygen, nitrogen and argon in the soil gas to determine if the biogas is diluted or undiluted; *(2)* measuring differential pressures; *(3)* measuring methane at additional locations to determine the spatial distribution of methane in the subsurface and better characterize the potential volume/mass of methane present; *(4)* repeat measurements to help identify and quantify temporal variability of methane concentrations and pressures; and/or *(5)* collecting data to estimate methane emissions and flux (CA DTSC, 2012) (see Appendix X4).

6.3.2.1 The amount of additional measurement data needed will depend on the initial evaluation of hazard and consistency of site measurements with the CSM. In general, the greater the uncertainty and potential risk, the more likely additional data will be needed.

6.3.2.2 If the data evaluation indicates data gaps, collect additional soil gas or other data and reevaluate based upon Fig. 1 and Table 1. Considerations for sampling and analysis are provided in Section 7 and the Bibliography.

6.3.3 *Special Case Evaluation (Tier 3)*—Some sites will require further investigation beyond the refined site evaluation because of remaining data gaps, certain atypical features of the CSM (for example, preferential pathways), or other risk management considerations. These sites should be evaluated on a case-by-case basis by an experienced professional. Such evaluations are outside the scope of this guide.

6.3.4 If there is still uncertainty, more advanced methods of site analysis may be used, such as *(1)* mathematical modeling, *(2)* continuous monitoring techniques, or *(3)* other acceptable methods. See the Bibliography.

6.4 *Exiting the Investigative Phase*—Exit points are summarized in Fig. 1 and Table 1. At any time, if there is still uncertainty in whether hazard exists, or if it is simply not desired to do further site evaluation, then mitigation or continued monitoring can be considered.

6.5 *Hazard*—Methane is not flammable directly within a typical soil matrix; the primary hazard is the flammability of methane in air (that is, in buildings). Methane in the soil gas is of concern if it migrates into enclosed spaces and mixes with air (including oxygen) to form a mixture within or above the flammable range: 5 to 15 %.

6.6 *Classify Sites and Situations*—A classification, or ranking, system is applied based on the potential hazard and the urgency of need for response action (see Fig. 1). The classification is based on information collected and reviewed during the site evaluation or refined site evaluation. Response actions are associated with classification and are to be implemented concurrently with an iterative process of continued assessment and evaluation. The classification system is applied at the initial stage of the process and also at any stage of the process in which site conditions change or new information is added. As the user gathers data, site conditions are evaluated and an initial response action implemented consistent with site conditions. The process is repeated when new data indicates a significant change in site conditions. Site urgency classifications are indicated in Table 1 along with example initial response actions. The user should select a response action option that best addresses the short-term concerns for the site. Note that the initial response actions listed in Table 1 are not necessarily comprehensive or applicable for all sites. Actual emergency response to an ongoing incident involves measurement of ambient gas levels at structures, points of emission from ground surface, etc. Normally, fire department and/or emergency response professionals will be involved in this effort and decision making. Emergency response monitoring is beyond the scope of this guide.

6.7 *Implement Response Action, if Applicable*—Response actions are selected to mitigate the identified hazard at the identified receptor. Consult Guide E2600 regarding mitigation of soil vapor hazard.

6.7.1 If the methane evaluation parameters are above levels of concern at the receptor points, along the transport pathway, or in primary source zones, the user develops measures designed to mitigate the hazard at the exposure point.

6.7.2 Hazard may also be mitigated by eliminating or controlling conditions at the exposure point, along the transport pathway, or in the primary source zone.

6.7.3 The mitigation measures may be a combination of engineering controls or institutional controls.

6.7.4 Remediation, or source removal, is seldom done for methane in soil gas. Sources may be too large or too deep or remote (off-site), making source removal impossible or at least economically unfeasible.

6.7.5 Institutional controls include covenants, restrictions, prohibitions, and advisories, and may include requirements for mitigation at some point.

6.7.6 *Engineering Controls*—Mitigation is the normal method of dealing with methane soil gas (see Fig. 2). At new buildings, mitigation techniques include: *(1)* subslab membrane and vent piping and *(2)* intrinsically safe design features. Intrinsically safe design allows no vapor pathway from the soil to confined space. Methods may include well-ventilated crawl spaces, first-floor "open-air" garages, or well-ventilated podium structures including basements. At existing buildings, mitigation techniques include: *(1)* barriers, passive crack repair, or other pathway plugging; *(2)* passive venting; *(3)* active venting; *(4)* positive pressure HVAC systems; *(5)* gas extraction systems; and *(6)* louvers in non-conditioned space that may also be used to increase air exchange rates inside structures. If pathways are blocked or plugged, an alternate route for venting of blocked gases is needed. Existing buildings may have VOC or radon mitigation systems already installed. If vent piping is part of the design, then mitigation systems for VOCs or radon should also serve to control methane as well. The potential for vented vapors to exceed an LEL should be evaluated to determine if an upgrade to an explosion-proof fan is warranted.

6.7.7 *Performance Monitoring*—Monitoring of soil gas, membrane performance, and/or interior air gas may be done.

6.7.7.1 Interior air monitoring such as with electronic gas detectors can be useful but is not itself a mitigation of gas intrusions since the detectors do not serve to prevent gas from entering a structure. Gas detection coupled with alarms may mitigate hazard by warning occupants to evacuate a structure when hazardous conditions develop or are present.

6.7.7.2 Monitoring of gas concentrations or pressures or both below the slab of a structure may be useful in determining changing soil gas conditions and risk.

6.7.8 *No Further Action*—This decision may be reached at various points, including before or after mitigation or control measures have been implemented, or after some period of monitoring. This step may be determined at any stage, including without mitigation or control, after mitigation or control, or after some period of monitoring.

7. Procedures for Information Collection and Evaluation

7.1 *Information Needs for Site Assessment*—Gather and collect information necessary for site classification, initial response action, and comparison of data with screening criteria. Specific considerations follow.

7.1.1 *General Gas Data*—Review historical records, conduct site visits, conduct interviews, and consolidate a summary of any prior adverse events in the vicinity that might include: *(1)* complaints; *(2)* gas bubbles at ground surface after rainfall

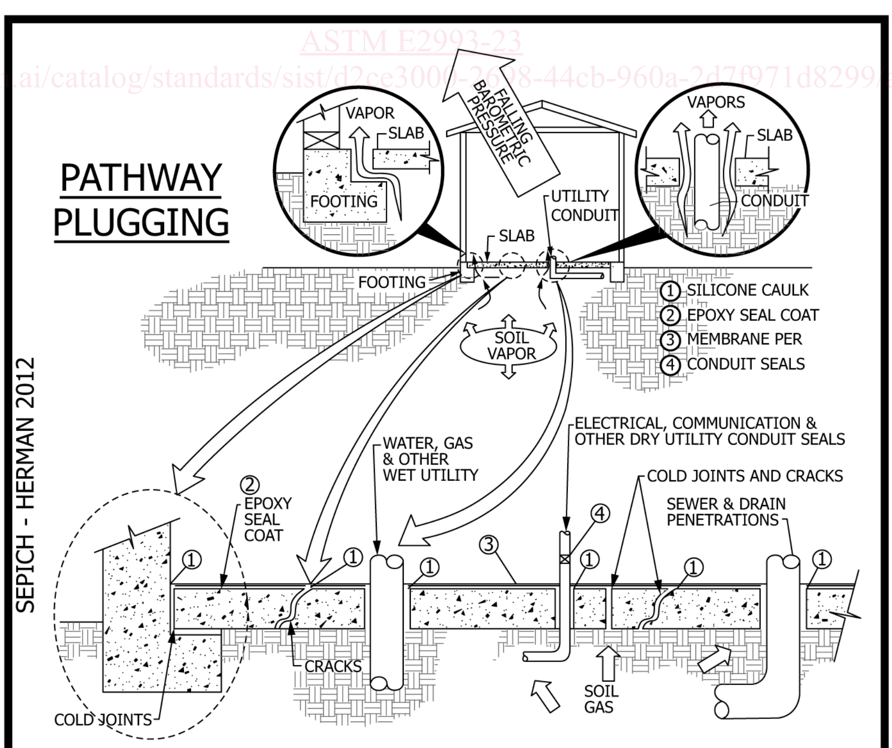

FIG. 2 Mitigation Method for Methane Soil Gas

or irrigation; *(3)* odors as a result of trace non-methane vapors; *(4)* seeping gas, seeping tar, and oily groundwater; *(5)* ignition at cracks in slab; *(6)* explosions; and *(7)* eruption of gas from geotechnical or other soil borings upon encountering free gas or supersaturated groundwater during drilling.

7.1.2 *Potential Gas Sources*—Identify major potential sources and contributing sources to methane in the subsurface. Sources of methane in the subsurface can include: municipal solid waste landfills, volcanic or other geothermal activity, petroleum gas reservoirs, very large subsurface releases of petroleum fluids, organic fill areas, bogs, swamps, wetlands, rice paddies, petroleum and gas seeps, natural gas pipeline and distribution systems, sewers, septic leachate fields, municipal sewers that include a high organic loading and leakage directly into the shallow subsurface, buried organic matter including vegetation, and other sources.

7.1.3 *Soils and Groundwater Data*—Identify relevant site and regional hydrogeological and geological characteristics, for example: *(1)* depth to groundwater, *(2)* soil type(s), *(3)* aquifer type and thickness, and *(4)* description of stratigraphy and confining units.

7.1.4 *Groundwater Gas Data*—Dissolved gas in groundwater has a bearing upon vadose zone gas concentrations. Ebullition (bubbling) from groundwater may occur if the dissolved gas is at a saturation limit (see Appendix X1). Quantifying the methane requires additional information on the occurrence of methane ebullition and, if so, the rate of methane gas flow, and is outside the scope of this guide. Groundwater methane concentration data alone cannot be directly correlated to unsaturated zone soil concentrations or the potential hazard from methane in buildings situated above the impacted groundwater. Saturated groundwater may pose a hazard if the groundwater is withdrawn for use. When the groundwater is no longer confined, the methane may volatilize and unacceptable indoor air concentrations may result in pump houses and other indoor spaces.

7.1.5 *Vadose Zone Gas Data*—Determine the methane evaluation parameters present in the subsurface and compare to levels of potential concern using the decision matrix (Table 1). Methane in the subsurface may be ubiquitous in soils under anoxic conditions. Methane concentration data alone is not sufficient to evaluate hazard from vadose zone gas. Soil gas pressures, direct flow measurements, soil types, pathways, receptors and other information are also necessary (see 6.1).

7.1.6 *Soil Gas Pathways*—Identify: *(1)* where methane gas may move directly into buildings, confined spaces, or tunnels or into subsurface structures (vaults, valve and meter boxes, ducts, conduits, vent pipes, sumps, sewers, and so forth); *(2)* situations in which a receptor (confined space) is exposed to a source of methane soil gas directly through air-connected soil porosity; and *(3)* preferential pathways such as coarse gravel backfill around utility lines leading to structures or large cracks or fractures in soil. Pathways may sometimes be discerned or assumed when elevated gas concentrations are found in vaults. Pathways may also be determined through evaluation of existing soils and geological reports for a site, the study of underground utility as-builts, or new investigations involving borings or trenching for observation of subsurface conditions.

7.1.7 *Gas Receptors and Points of Exposure*—Identify locations where hazard is of direct concern such as vaults, building interiors, tunnels, and any other confined spaces that are buried/below or above grade.

7.1.8 *Interior Gas Data*—Measure methane concentration at receptors and points of exposure (that is, in building or other enclosed spaces and structures) and compare to levels of concern, such as fraction of LEL. The design and operation of any HVAC system should be taken into account. Other considerations apply. See Table 1. Measurements outside a building or structure (for example, soil gas measurements) may be used to extrapolate or predict conditions inside the building or structure. Conservative attenuation factors can be used for the extrapolation or may be modified based on site-specific conditions.

7.2 *Guidelines for Test Probe Installation, Monitoring, Sampling, and Analysis:*

7.2.1 *Why to Sample Methane Soil Gas*—Combustible soil gas sampling can be triggered by changes in ownership or refinancing, change in land use, simultaneous with other site investigations, or by some field event or observation.

7.2.2 *Where to Sample Soil Gas*—Considerations include:

7.2.2.1 *Radius-Based Sampling*—In some jurisdictions, sampling for methane gas is typically done within prescribed distances from a methane source [for example, 305 m (1000 feet) of a sanitary landfill (County of Los Angeles Building Code Section 110); over or within 457 m (1,500 feet) of the administrative boundaries of an oilfield (City of Los Angeles methane buffer zone); or within some radius of an oil well, such as 8 to 61 m (25 to 200 feet; City of Los Angeles) or 107 m (350 feet; Orange County California)].

7.2.2.2 *Source Recognition Gas Sampling*—Often, there is no governance and the consultant should be aware of unregulated but known potential methane areas such as organic soils, swamps, marshes, and glacial till and any site where incidents or previous investigations and reports suggest the potential for combustible soil gas.

7.2.2.3 *Site Surface Features*—Consideration should be given to site specifics such as drainage patterns, location of hardscape and softscape, distance from structures, and any other site culture or conditions that may affect methane readings.

7.2.2.4 *Site Subsurface Features*—Consideration should be given to site specifics such as soils and geologic strata, groundwater and perched water depths, soil type, soil moisture, location of nearby underground utilities, and any other subsurface conditions that may affect methane readings.

7.2.2.5 *Vadose Zone Gas Sampling*—Methane samples are collected from various sources, including vadose zone push probes, vadose zone monitoring well head space and casing gas, landfill gas wells and pipelines, and oilfield hydrocarbon wells.

7.2.2.6 *Surface Sweeps*—Surface sweeps or screening may identify points of direct leakage and flow of soil gas from below grade to atmosphere or structure interiors. The finding of methane in surface sweeps may provide direct evidence of methane flow. Such findings should normally be followed up