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## Soil Guideline Values for benzene in soil

### Science Report SC050021 / benzene SGV

This technical note is one in a series that describe Soil Guideline Values (SGVs) for individual, or groups of similar, chemicals to assist in the assessment of risks from land contamination.

SGVs are an example of generic assessment criteria (Defra and Environment Agency, 2004) and can be used in the preliminary evaluation of the risk to human health from long-term exposure to chemicals in soil. Specifically, this note provides SGVs for benzene in soil.

The SGVs and the additional advice found here should be used only in conjunction with the introductory guide to the series entitled *Using Soil Guideline Values* (Environment Agency, 2009a), the framework documents *Updated technical background to the CLEA model* (Environment Agency, 2009b) and *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c), and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Benzene* (Environment Agency, 2009d). Supplementary information on benzene is also available (Environment Agency, 2008, 2009e).

All notes in the SGV series, the introductory guide and further supplementary information can be downloaded from our website (<http://www.environment-agency.gov.uk/clea>).

### Benzene

Benzene (CAS No. 71-43-2), also known as benzol, is a naturally occurring aromatic hydrocarbon with a sweet odour (ATSDR, 2007). Pure benzene is a clear, colourless, volatile liquid (at room temperature and ambient pressure) which is highly flammable (ATSDR, 2007; ECB, 2007). It is slightly soluble in water but is easily miscible with most organic solvents (IPCS, 1993; ATSDR, 2007; ECB, 2007).

Benzene, toluene, ethylbenzene and xylene are often referred to collectively as BTEX because they have closely related chemical structures, and have similar fate and transport properties.

They are often used together in industrial and petroleum products, and commonly occur together in the environment as a result of related pollution.

Benzene is naturally present in emissions from volcanoes and forest fires. It is also a constituent of crude oil (ATSDR, 2007; ECB, 2007). However, releases to the environment from these sources are small compared with anthropogenic inputs (ATSDR, 2007).

Because benzene is an intrinsic component of crude oil, it is present in refinery products. It is also an important industrial chemical and is produced commercially by recovery from both petroleum and coal sources and from condensate from natural gas production (ATSDR, 2007; ECB, 2007). The majority of benzene is recovered from the petrochemical and petroleum refining industries where sources include refinery streams (catalytic reformats), pyrolysis of petrol and toluene hydrodealkylation (ATSDR, 2007). The major impurities found in commercial benzene are toluene, xylene, phenol, thiophene, carbon disulphide, acetylnitrile and pyridine (ATSDR, 2007).

Benzene is used throughout the world in enormous quantities. Other than its use as an additive to petrol, the vast majority of benzene produced is used as a chemical intermediate in the production of other chemicals: ethylbenzene (used to make styrene), cumene (used to make phenol and acetone), cyclohexane (used to make nylon), nitrobenzene, alkylbenzene, maleic acid anhydride and chlorinated benzenes (IPCS, 1993; ATSDR, 2007; ECB, 2007). The estimated annual production of benzene as a chemical intermediate in the European Union is around 5.8–7.2 million tonnes (ECB, 2007).

Historically, benzene was widely used as a solvent in manufacturing processes and consumer products. Its use in this way has declined in recent years and this accounts for a very small proportion of current use (IPCS, 1993; ATSDR, 2007; ECB, 2007).

Uses as a solvent include/included: in the manufacture of products such as solvents, industrial paints, rubber cements, adhesives, paint removers and degreasing agents; in the production of artificial leather and rubber goods and in the shoe industry.

Benzene is also added to petrol to improve the octane rating (ATSDR, 2007). The European petrol quality requirements limit benzene in petrol to a maximum of one percent by volume (ECB, 2007). Annual consumption of petrol across the EU (1990-1994) was about 120 million tonnes with approximately 1.41 million tonnes of benzene consumed per year in petrol (ECB, 2007).

## Potential harm to human health

The principles behind the selection of Health Criteria Values (HCVs), and the definition of concepts and terms used, are outlined in *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c). Specific information on the toxicity of benzene and its compounds is reviewed in *Contaminants in soil: updated collation of toxicological data and intake values for humans. Benzene* (Environment Agency, 2009d) and only a brief summary is presented here.

The blood and immune system are the main targets of chronic exposure to benzene. The critical effect of both oral and inhalation exposure is considered to be the potential for leukemia (Environment Agency, 2009d).

An Index Dose ( $ID_{inh}$ ) derived on the basis of minimal risk in accordance with the principles described in the toxicological framework report (Environment Agency, 2009c), would be about  $0.5\text{--}0.9\ \mu\text{g kg}^{-1}\ \text{bw day}^{-1}$ . However, the Air Quality Objective (AQO) for benzene in England and Wales of  $5\ \mu\text{g m}^{-3}$  is equivalent to a higher intake of approximately  $1.4\ \mu\text{g kg}^{-1}\ \text{bw day}^{-1}$  (Environment Agency, 2009d).

In accordance with *Guidance on the legal definition of contaminated land* (Defra, 2008), the toxicological framework report (Environment Agency, 2009c) notes that:

"If a guideline for a non-threshold carcinogen has been produced under a different regulatory regime with UK jurisdiction that is less stringent than the derived ID [Index Dose], it may be considered disproportionate to enforce a stricter limit for contaminated land, and therefore inappropriate to set the SGV [Soil Guideline Value] on the derived ID. In such instances, the ID and SGV may be set based on equivalence to the existing guideline."

This is the case for the inhalation Index Dose ( $ID_{inh}$ ) for benzene used in the derivation of the SGVs in this report. A health-based  $ID_{inh}$  derived on the basis of minimal risk in accordance with the principles described in the toxicological framework report (Environment Agency, 2009c) would be more stringent than the intake of benzene from ambient air based on the AQO for benzene in England and Wales (Defra, 2007). Therefore, in order to avoid disproportionately targeting

exposures from soil, an  $ID_{inh}$  based on the AQO is used in SGV derivation.

The ID for deriving SGVs for benzene are summarised in Table 1.

**Table 1**

Recommended Health Criteria Values for benzene (Environment Agency, 2009d)<sup>1</sup>

Parameter	Benzene
$ID_{oral}, \mu\text{g kg}^{-1}\ \text{bw day}^{-1}$	0.29
$ID_{inh}$ for deriving SGV, $\mu\text{g kg}^{-1}\ \text{bw day}^{-1}$	1.4 <sup>2</sup>

Notes      <sup>1</sup> MDI data are not reproduced here as the HCVs for benzene are Index Doses.  
<sup>2</sup> Based on the 2010 AQO for benzene in England and Wales.

AQO = Air Quality Objective  
 bw = bodyweight  
 ID = Index Dose

The oral Index Dose ( $ID_{oral}$ ) in Table 1 is based on the World Health Organization (WHO) guideline for drinking-water quality for benzene, which was estimated to be associated with a lifetime excess leukaemia risk of 1 in 100,000 (Environment Agency, 2009d).

No expert group derivations of HCVs for dermal exposure have been identified for benzene (Environment Agency, 2009d). Dermal absorption of benzene is considered to be very low (Environment Agency, 2009b). On this basis, it would not seem unreasonable to assume that the oral ID for deriving SGVs could be used for an initial conservative dermal risk assessment, in line with Environment Agency (2009c).

Background inhalation exposure to benzene from its presence in ambient air is estimated to be approximately  $200\ \mu\text{g day}^{-1}$  for an adult weighing 70 kg and inhaling  $20\ \text{m}^3\ \text{day}^{-1}$ . Concentrations indoors were reported to be higher than those outdoors by a factor of two, and rural concentrations were lower than urban concentrations (Environment Agency, 2009d). Sources not included in the background estimations include benzene in mainstream cigarette smoke, and benzene in air at localised areas of higher concentrations such as petrol stations and areas of industrial solvent manufacture/storage.

Benzene was not found above the limit of detection in a number of foodstuffs analysed by the then Ministry of Agriculture, Fisheries and Food (MAFF, 1995). Similar findings were made regarding drinking-water (Environment Agency, 2009d). The background oral exposure from its presence in food and water is estimated at  $3\ \mu\text{g day}^{-1}$  (Environment Agency, 2009d).<sup>1</sup>

<sup>1</sup> Because the HCVs for benzene are Index Doses, background exposure is not considered in SGV derivation.

## Exposure assessment

### Occurrence in soil

Most soils will contain very little, if any, benzene as a result of natural processes.

Benzene is released to the soil environment through industrial discharges, waste disposal, fuel leaks or spillages (IPCS, 1993; ATSDR, 2007). Leaks or spillages of petroleum, and solvent products from historical use and poor management practice, often result in persistent contamination over a wide area. Benzene is a component of complex and weathered mixtures of hydrocarbon compounds and may exist in soil as a degradation by-product.

A review of the literature identified no data on background levels of benzene in UK soils. A similar conclusion was drawn by Paterson *et al.* (2003) in work commissioned by the Scottish Environment Protection Agency (SEPA). According to Wolverhampton City Council (personal communication, 2009), average background concentrations of benzene in glacial drift deposits on a large housing estate in an urban area of the West Midlands were below the detection limit of  $1 \mu\text{g kg}^{-1}$ .

Limited data were found regarding background concentrations in soil in other European countries. The International Programme on Chemical Safety (IPCS) reported that benzene concentrations in unspecified soils in the Netherlands were low (IPCS, 1993). The European Chemicals Bureau (ECB) reported that concentrations of benzene in soil were expected to result from atmospheric deposition (ECB, 2007). ECB estimated the background soil concentration across Europe to be  $0.02 \text{ mg kg}^{-1}$  on the basis of known releases of benzene into the environment and its modelled behaviour (Environment Agency, 2003).

### Behaviour in the soil environment

Recommended values for chemical data used in the exposure modelling of benzene are provided in Table 4. Further information about the selection of chemical properties for benzene can be found in Environment Agency (2008). *Supplementary information for the derivation of SGV for benzene* (Environment Agency, 2009e) provides additional information about the review and recommendations for the soil-to-plant concentration factors for benzene.

Benzene is considered by most authoritative organisations to be mobile in the soil environment (IPCS, 1993; ATSDR, 2007).

Upon release into the soil environment, benzene will tend to sink through the unsaturated zone until it reaches the saturated zone (Environment Agency, 2003). It is a light non-aqueous phase liquid (LNAPL) and will tend to collect at the water table if present in sufficient concentrations.

Benzene can easily leach from soil based on its aqueous solubility, molecular weight and octanol-water partition coefficient ( $K_{ow}$ ) (IPCS, 1993; Environment Agency, 2003; ATSDR, 2007). Benzene has a moderate

tendency to adsorb to SOM (reflected by its organic carbon water partition coefficient,  $K_{oc}$ ). The sorption potential also varies with other soil properties (e.g. water content, number of adsorption sites and porosity) and environmental conditions (e.g. temperature) (Environment Agency, 2003). In general, for benzene, adsorption is a faster process than desorption (ATSDR, 2007).

Benzene will readily volatilise from surface soil given its high vapour pressure, high air–water partition coefficient and moderate  $K_{oc}$  (IPCS, 1993; Environment Agency, 2003). Volatilisation from the sub-surface to air is the most important of the transport processes for benzene (IPCS, 1993; ATSDR, 2007), though the rate of volatilisation will decrease at greater depths. Benzene will volatilise more readily from soils with a high air-filled porosity such as sands and gravels (Environment Agency, 2003).

Benzene is subject to microbial degradation under both aerobic and anaerobic conditions (IPCS, 1993; ATSDR, 2007); the former is typically much more rapid (Environment Agency, 2003). However, studies on the biodegradation of benzene have been limited by the volatilisation of benzene during the study period; benzene did not remain in soil long enough for significant biodegradation to occur (IPCS, 1993).

Biodegradation rates are dependent on several factors including: the presence of sunlight; the type and population of microbes present; initial concentration of benzene; soil temperature; soil oxygen content; and the potential presence of other electron receptors<sup>2</sup> (Environment Agency, 2000a, 2003).

Limited data were found regarding the degradation half-life<sup>3</sup> of benzene in soil. Although there is evidence that benzene degrades in soil, degradation in water is more commonly studied. ECB (2002) proposed a half-life of 30 days for benzene in soil based on tests conducted from the water phase. A report prepared for the US

#### Effect of mixtures on degradation of benzene

When mixtures of benzene, toluene, xylene and ethylbenzene (BTEX) are present in an anaerobic environment, there is a sequential utilisation of the substrate hydrocarbons, with toluene usually being the first to be degraded, followed by the isomers of xylene in varying order. Benzene and ethylbenzene tend to be degraded last (ATSDR, 2007).

<sup>2</sup> Electron acceptors are compounds which are capable of accepting electrons during oxidation–reduction reactions. Microbes obtain energy by transferring electrons from electron donors such as benzene to an electron acceptor (Environment Agency, 2000a). Typical electron acceptors found in soil include dissolved oxygen, nitrate, sulphate, iron, manganese and carbon dioxide (Environment Agency, 2000a)

<sup>3</sup> These reported half-lives may also include other loss processes besides biodegradation.



Environmental Protection Agency (USEPA) describes a number of half-life studies based on laboratory investigations.

These are not discussed here as the optimised conditions mean that the half-lives and thus degradation potential are not comparable with a real soil environment. Half-lives from groundwater studies are also not discussed further as oxygen is often the rate limiting parameter for biodegradation. Results may therefore not be applicable to aerobic soils due to more rapid biodegradation (USEPA, 1999).

Key aspects of benzene's behaviour in the soil environment will be influenced by the presence of other compounds. The solubility and volatility of benzene are reported to decrease in the presence of other hydrocarbon compounds and after weathering of the hydrocarbon compounds has taken place (TPHCWG, 1998).

Modelling the partitioning of volatile organic compounds (VOCs) such as benzene from soil to ambient or indoor air is subject to a number of simplifications and limitations (CIRIA, in press). Many environmental models, including the CLEA model, predict chemical concentrations in soil systems using simple linear partitioning models. CIRIA (in press) reports empirical data from a large number of site investigations in the US and UK which illustrates that this approach is conservative for many petroleum hydrocarbons across different situations and soil types.

Although the reasons for the difference between empirical and theoretical calculations is the subject of continued debate (CIRIA, in press), reported factors include sampling technique, biodegradation in the vapour phase, and natural ground heterogeneity. As soil vapour is transported upwards towards the building, biodegradation of petroleum hydrocarbons commonly occurs which can significantly affect the amount of vapour that will enter the building. Among other factors, this is dependent on the oxygen availability in the unsaturated zone (CIRIA, in press).

Using simple linear partitioning, the concentrations of petroleum hydrocarbons in the soil gas can be over-predicted by at least a factor of 10 (and up to a factor of 1,000) (Environment Agency, 2009b; CIRIA, in press).

Given the likely level of overprediction reported in empirical studies, it is not unreasonable to include a sub-surface soil to indoor air correction factor of 10 in the derivation of SGVs for benzene. This is the lower end of the range of over-predictions reported and, therefore, sufficiently conservative to be appropriate to use in a generic screening value.

Benzene is moderately hydrophobic based on its  $K_{ow}$  (Environment Agency, 2003). The uptake into plants from soil therefore has the potential to occur directly through the roots (from which benzene is transported throughout the plant), or indirectly following volatilisation of benzene from the soil and subsequent vapour phase sorption by plant surfaces (Environment Agency, 2009e). On entering the leaves, benzene may be lost

through transpiration or metabolised (Environment Agency, 2009e).

Data on the adverse effects of benzene to plants are not widely documented. Available studies indicate that benzene can cause damaging effects in plants, but this is dependent on the soil type, benzene concentration in soil, and plant species. Adverse effects on root growth, plant growth and cellular damage have been reported (Environment Agency, 2009e).

In the absence of sufficient data to specify soil-to-plant concentration factors for benzene, Environment Agency (2009e) recommends that the generic CLEA models for calculating soil-to-plant concentration factors are used in the derivation of SGVs.<sup>4</sup>

A review of the literature did not identify any studies for quantifying the dermal absorption fraction for benzene and therefore the default value of 0.1 proposed by Environment Agency (2009b) for organic compounds was used in the derivation of the SGVs.

A review of the literature found no data relevant to estimating the concentration of benzene in household dust from any sources, including soil. The default value of  $0.5 \text{ g g}^{-1}$  dry weight (DW) for the soil-to-dust transport factor was used in the derivation of the SGVs (Environment Agency, 2009b). This is considered to be a sufficiently conservative assumption.

## Soil Guideline Values

Soil Guideline Values for benzene are presented according to land use in Table 2. For the residential and allotment land uses, SGVs are based on estimates representative of exposure of young children because they are generally more likely to have higher exposures to soil contaminants. Further information on the default exposure assumptions used in the derivation of SGVs can be found in *Updated technical background to the CLEA model* (Environment Agency, 2009b).

The SGVs for benzene given in Table 2 are based on a consideration of the oral, dermal and inhalation routes of exposure. The toxicological effects are considered to be systemic and the combined assessment criteria are presented.

<sup>4</sup> In the absence of suitable models for shrub fruit and herbaceous fruit (Environment Agency, 2009b), exposure from ingestion of shrub and herbaceous fruits was not included in the derivation of the SGVs.

**Table 2**

The Soil Guideline Values for benzene presented in this table should only be used in conjunction with the information contained in this technical note and with an understanding of the exposure and toxicological assumptions contained in *Updated technical background to the CLEA model* (Environment Agency, 2009b), *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c) and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Benzene* (Environment Agency, 2009d).

Land use	Soil Guideline Value (mg kg <sup>-1</sup> DW) <sup>1,2,3,4,5</sup>
	<b>Benzene</b>
Residential	0.33
Allotment	0.07
Commercial	95

- Notes
- <sup>1</sup> Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% soil organic matter (SOM). At a lower SOM, SGVs may not be sufficiently protective.
  - <sup>2</sup> Generic assessment criteria (GAC) for benzene will vary according to SOM for all land uses.
  - <sup>3</sup> Figures are rounded to one or two significant figures.
  - <sup>4</sup> SGVs assume that free phase contamination is not present.
  - <sup>5</sup> SGVs based on a subsurface soil to indoor air correction factor of 10.

DW = dry weight

The percentage of exposure at the SGV attributable to each individual relevant pathway for each land use is presented in Table 3. The ADE/ID for deriving SGV ratios for oral and inhalation exposures are also presented. Modelling suggests that:

- the inhalation of indoor vapour and the consumption of homegrown produce pathways contribute the most exposure at the SGV for the residential land use (approximately seventy per cent and thirty per cent, respectively, of total exposure).
- the consumption of homegrown produce is the most significant exposure pathway at the SGV for the allotment land use;
- the inhalation of indoor vapour is the most significant exposure pathway at the SGV for the commercial land use;
- the exposure via dermal pathways is negligible, contributing less than one per cent of total exposure at the SGVs for all land uses;

- the inhalation of dust pathway is not an important exposure pathway. This is due to the significant tendency of benzene to volatilise from soil water into soil air, and its moderate preference to adsorb to soil organic matter.

The derivation of the benzene SGVs does not use a health-based ID<sub>inh</sub> derived on the basis of minimal risk because this would be more stringent than the intake of benzene from ambient air at the Air Quality Objective (AQO) for benzene in England and Wales. In order to avoid disproportionately targeting exposures from soil, the ID<sub>inh</sub> is derived from the AQO. The SGVs in Table 2 are unlikely to represent a significant possibility of significant harm. However, the likelihood of an exceedance of an SGV in Table 2 representing a significant possibility of significant harm may be greater than if the ID<sub>inh</sub> had been based purely on health-based considerations of minimal risk.

Analytical limits of detection<sup>5</sup> for benzene depend on the analytical technique used and range from 0.001 to 0.010 mg kg<sup>-1</sup> DW, with limits of quantification<sup>6</sup> ranging from 0.005 to 0.050 mg kg<sup>-1</sup> DW. Limits of detection and quantification can vary due to the range, sensitivity, set-up of the instrumentation being used and the sample matrix. MCERTS<sup>7</sup> accredited analytical methods for testing for benzene in soil are available.

It is anticipated that benzene will not form free phase product at soil concentrations lower than the SGVs<sup>8</sup>. The potential for free phase product should be assessed at the preliminary stage of risk assessment when formulating the outline conceptual model, as outlined in Defra and Environment Agency (2004). For example, maps may show the presence of tanks or anecdotal information may indicate that spills might have occurred at the site. The SGVs in Table 2 should be applied cautiously where free phase contamination is suspected (e.g. by taking into account visual and olfactory observations) and its potential presence at the surface should be considered qualitatively as part of the risk assessment. In such cases, alternative methodologies such as those which model vapours from non-aqueous phase liquids (NAPLs), or a consideration of dermal contact with NAPLs may be more suitable (Environment Agency, 2009f).

Ingestion of drinking-water contaminated from on site sources is not an exposure pathway included in the CLEA model (Environment Agency, 2009b). Environment Agency (2000b) and WRAS (2002) identify petroleum hydrocarbon compounds including benzene as having the potential to permeate certain types of plastic water pipes. Pipe permeation is especially likely to occur where there is prolonged contact with heavily contaminated soils which may include the presence of free phase. Permeation is dependent on several factors

<sup>5</sup> The amount of a substance that can be detected but not measured quantitatively.

<sup>6</sup> The amount present of a substance that can be measured quantitatively.

<sup>7</sup> Environment Agency's Monitoring Certification Scheme

<sup>8</sup> The lower of the vapour and aqueous saturation concentration for benzene is 4,360 mg kg<sup>-1</sup>

such as the chemical characteristics of the contaminant mixture present, the water content of the soil, the distribution between the soil, air and vapour phases (mobility and  $K_{oc}$ ), length of exposure and temperature (DWI, 1997).

RIVM (1995) proposed a method of estimating pipe permeation, although this is highly uncertain and the assessment will depend on the type of pipe work found, water usage and the soil concentration immediately adjacent to the pipe wall.

It is unlikely that soil concentrations of benzene at the level of the residential or allotment SGVs will pose a significant additional risk to health from this pathway. However, where contamination is found or is suspected close to buried water services, the risk assessor should consider its implications carefully and, where necessary, investigate the likelihood of contamination of the water supply.

The generic conceptual exposure models used to derive SGVs (as described in Environment Agency, 2009b) assume that:

- the source term is infinite;
- the source term is not itself reduced by biological or chemical degradation;
- benzene is present in isolation and not in a mixture with other compounds.

Assessors undertaking a Detailed Quantitative Risk Assessment (DQRA) (Defra and Environment Agency, 2004) may wish to consider the applicability of these assumptions on a site-specific basis. The actual degradation half-life of a chemical in soil is highly site-specific and dependent on a number of influences including soil temperature, oxygen availability, microbial population and the presence of other contaminants.

It is highly unusual for benzene to occur in isolation in a contaminated soil, although fate and transport calculations (such as those used by the CLEA model) normally assume single component behaviour. Its environmental behaviour will be influenced by the presence of other compounds in the mixture (TPHCWG, 1998; ATSDR, 2007). The assessor should consider the effects of other substances on the mobility of benzene as part of a Detailed Quantitative Risk Assessment. For example, when the inhalation of vapour is a key pathway, assessors may wish to use Raoult's Law to determine the effective vapour concentration of benzene in the mixture (TPHCWG, 1999, Environment Agency, 2003).

The phytoavailability of benzene to garden produce depends on a number of complex factors. The soil-to-plant concentration factors used in the derivation of the SGVs are calculated from generic algorithms (detailed in Environment Agency, 2009b) for a generic scenario and some are dependent on the  $K_{ow}$  of benzene (that is, the degree to which benzene partitions between water and plant lipids). Plant uptake of benzene may be limited by degradation of benzene in soil and therefore calculations based on physical-chemical properties may over-predict

uptake by plants from soil (Environment Agency, 2006, 2009e).

In circumstances where the SGV is exceeded and the consumption of produce is a significant pathway, assessors may wish to adjust for the site-specific measured SOM. A higher SOM will mean that less benzene is available for plant uptake because it remains sorbed to the soil.

Assessors undertaking a Detailed Quantitative Risk Assessment could also carry out further investigation (including the sampling and chemical analysis of edible parts of fruits and vegetables) to determine site-specific plant concentration factors. Herbaceous and shrub fruit produce groups have not been modelled in the derivation of SGVs (Environment Agency, 2009b). In cases where these predominate the total fruit and vegetables consumed from a site, further consideration is necessary. However, the sampling and chemical analysis of edible parts of fruits and vegetables is unlikely to be an easy task.

Environment Agency (2009b) highlights some uncertainties in the Johnson and Ettinger algorithms used to estimate the concentrations within indoor air. It is recognised that the concentration of petroleum hydrocarbons within the building may be overestimated using this approach.

A number of factors contribute significantly to the amount of benzene that will partition into the soil vapour phase, including SOM (sorption to organic matter retards volatilisation). When the inhalation of indoor air is the pathway driving the risk, those undertaking a DQRA could carry out further assessment such as soil vapour monitoring. Further guidance and information can be found in CIRIA (in press).

As noted above, SOM content may affect the vapour inhalation and plant uptake pathways significantly. SGVs are based on a SOM content of 6 per cent. At lower SOM, they may not be sufficiently protective.

Exposure from dermal contact and direct soil ingestion pathways may be important in scenarios where the vapour pathway is actively or passively managed by, for example, the building design. Further discussion of these pathways can be found in Environment Agency (2009b).



**Table 3**

Contribution to exposure from soil for the relevant pathways as calculated by the CLEA software

	<b>ADE:ID for deriving SGV' ratio</b>		
	<b>Residential</b>	<b>Allotment</b>	<b>Commercial</b>
Oral ADE:ID ratio at SGV	0.68	1.0	0.17
Inhalation ADE:ID ratio at SGV	0.32	0	0.83
	<b>Contribution to exposure<sup>1</sup> from soil according to land use (%)</b>		
<b>Exposure pathway</b>	<b>Residential</b>	<b>Allotments</b>	<b>Commercial</b>
Ingestion of soil and indoor dust <sup>2</sup>	0.4	0	3.5
Consumption of homegrown produce and attached soil	30.0	99.9	NA
Dermal contact (indoor)	0	NA	0.2
Dermal contact (outdoor)	0.2	0	0.4
Inhalation of dust (indoor)	0	NA	0
Inhalation of dust (outdoor)	0	0	0
Inhalation of vapour (indoor)	69.4	NA	95.4
Inhalation of vapour (outdoor)	0	0.1	0.5

Notes <sup>1</sup> Rounded to one decimal place.<sup>2</sup> Treated as one pathway (see Environment Agency, 2009b).

ADE = Average Daily Exposure

ID = Index Dose

NA = not applicable (This exposure pathway is not included in the generic land use.)

**Table 4**

Recommended chemical data for benzene (at 10°C unless stated)

Chemical property	Benzene	
Air–water partition coefficient, dimensionless	0.116	Environment Agency (2008)
Dermal absorption fraction, dimensionless	0.1	Environment Agency (2009b)
Diffusion coefficient in air, $\text{m}^2 \text{s}^{-1}$	$8.77 \times 10^{-6}$	Environment Agency (2008)
Diffusion coefficient in water, $\text{m}^2 \text{s}^{-1}$	$6.64 \times 10^{-10}$	Environment Agency (2008)
Octanol–water partition coefficient (log), dimensionless	2.13	Environment Agency (2008)
Organic carbon–water partition coefficient (log), $\text{cm}^3 \text{g}^{-1}$	1.83	Environment Agency (2008)
Relative molecular mass, $\text{g mol}^{-1}$	78.11	Environment Agency (2008)
Soil–water partition coefficient, $\text{cm}^3 \text{g}^{-1}$	NA	
Vapour pressure, Pa	6,240	Environment Agency (2008)
Water solubility, $\text{mg L}^{-1}$	1,780	Environment Agency (2008)
Soil-to-dust transport factor, $\text{g g}^{-1} \text{DW}$	0.5	Environment Agency (2009b)
Sub-surface indoor air correction factor	10	Recommended in this report
Soil-to-plant concentration factor, $\text{mg kg}^{-1} \text{FW per mg kg}^{-1} \text{DW}$		
Green vegetable produce	To be modelled	Environment Agency (2009e)
Root vegetable produce	To be modelled	Environment Agency (2009e)
Tuber vegetable produce	To be modelled	Environment Agency (2009e)
Herbaceous fruit produce	To be modelled	Environment Agency (2009e)
Shrub fruit produce	To be modelled	Environment Agency (2009e)
Tree fruit produce	To be modelled	Environment Agency (2009e)

Notes <sup>1</sup> Algorithms are not presented in Environment Agency (2009b) for herbaceous and shrub fruit. Exposure from these pathways was therefore not considered in the derivation of the SGVs.

DW = dry weight

FW = fresh weight

NA = not applicable



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The CLEA Guidance incorporates the following

- 1) *Science Report SC050021/SR2: Human health toxicological assessment of contaminants in soil.*
- 2) *Science Report SC050021/SR3: Updated technical background to the CLEA model.*
- 3) *Science Report SC050021/SR4: CLEA Software (Version 1.04) Handbook.*
- 4) *CLEA Software version 1.04 (2009)*
- 5) *Toxicological reports and SGV technical notes*

The CLEA Guidance can help suitably qualified assessors to estimate the risk that a child or adult may be exposed to a soil concentration on a given site over a long period of exposure that may be a cause for concern to human health. The CLEA Guidance does not cover

other types of risk to humans, such as fire, suffocation or explosion, or short-term and acute exposures. Nor does it cover risks to the environment or the pollution of water.

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The CLEA guidance describes the soil concentrations above which, in the opinion of the Environment Agency, there may be concern that warrants further investigation and risk evaluation for both threshold and non-threshold substances. These levels are a guide to help assessors estimate risk. It does not provide a definitive test for telling when risks are significant.

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