

**Department for Environment, Food and Rural Affairs
and the Environment Agency**

**CONTAMINANTS IN SOIL:
COLLATION OF TOXICOLOGICAL DATA AND
INTAKE VALUES FOR HUMANS.
BENZO[*a*]PYRENE**

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Statement of Use

This publication details the derivation of Index Doses for benzo[*a*]pyrene. The report has been written for technical professionals who are familiar with the risks posed by land contamination to human health but who are not necessarily experts in risk assessment. It is expected to be of use to all parties involved with or interested in contamination, but in particular to those concerned with the assessment of land contamination.

Keywords

Tolerable daily intake, tolerable soil daily intake, Index Dose, land contamination, risk assessment, human health, polycyclic (or polynuclear) aromatic hydrocarbons, benzo[*a*]pyrene.

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1 Introduction

- 1.1 This report, one of a number on the assessment of risks to human health from contaminants in soil, presents key data and expert opinions on the toxicology and intake of benzo[a]pyrene (BaP). It may be necessary to update this document in the future and incorporate new toxicological data as science advances.
- 1.2 It is assumed that there is no “threshold” dose of BaP which is harmless. The aim therefore was to derive Index Doses which in turn are needed to derive Soil Guideline Values for BaP, which are concentrations in soil that will pose no significant threat to health.
- 1.3 There is a general discussion of Index Doses in CLR9 *Contaminants in Soils: Collation of Toxicological Data and Intake Values for Humans. Consolidated Main Report* (DEFRA and Environment Agency, 2002a). Reference to CLR9 is necessary to understand the concepts and terms used in this report.
- 1.4 The computer model used for deriving Soil Guideline Values is described in CLR10 *The Contaminated Land Exposure Assessment Model (CLEA): Technical Basis and Algorithms* (DEFRA and Environment Agency, 2002b). The derivation of the Soil Guideline Values for BaP is given in *SGV 2 Guideline Values for Benzo[a]Pyrene Contamination in Soils* (DEFRA and Environment Agency, in prep).
- 1.5 As soils will contain not just BaP but an array of polycyclic aromatic hydrocarbons (PAHs), it is important that the toxicological significance of the whole PAH mixture is taken into account. Advice on assessing human health risks from mixtures is provided in a recent review to be published shortly *Dealing with Mixtures of Contaminants in Soils* (Environment Agency, in prep). DEFRA and the Environment Agency will be publishing health criteria and Soil Guideline Values for other relevant PAHs.
- 1.6 The literature up to January 2002 has been reviewed in this report.

2 Identity and Sources

- 2.1 Polycyclic (or polynuclear) aromatic hydrocarbons (PAHs) are a large group of hydrocarbons containing two or more benzene rings fused to each other or to other hydrocarbon rings. They are formed mainly as a result of pyrolytic processes, especially the incomplete combustion of organic materials. Man-made sources include motor vehicle engines, coal and wood fires, refuse incineration and cigarette smoke; PAHs are also present in many foodstuffs. Natural sources include volcanoes and forest fires. Crude oil, shale oil and coal tar contain small amounts of PAHs (ATSDR, 1995).
- 2.2 There are many hundreds of individual PAH compounds – about 50 have been identified at hazardous waste sites in the USA (ATSDR, 1995), and about 500 have been identified in the atmosphere (WHO, 1987). Benzo[*a*]pyrene (BaP) is easily the most well studied PAH.
- 2.3 BaP, also known as 3,4-benzopyrene or 6,7-benzopyrene, is a five-ringed PAH. It is a yellowish solid, melting at 178°C, with a very low vapour pressure (7.3×10^{-7} Pa at 25°C) and low water solubility ($3.8 \mu\text{g L}^{-1}$ at 25°C) (WHO, 1998a).

3 Toxicity

- 3.1 This section (and Section 4) are based on an identification and description of the key studies cited in the reviews undertaken by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (WHO, 1991a), the Agency for Toxic Substances and Disease Registry (ATSDR, 1995), several WHO Task or Working Groups (WHO, 1987, 1993, 1996, 1998a,b, 2000), and the Working Groups of the International Agency for Research on Cancer (IARC, 1983, 1987) on the toxicity of either the PAHs in general or BaP specifically. In addition, information from the latest record on BaP in the Integrated Risk Information System (IRIS) (USEPA, 2001) has been included. The primary literature has generally not been consulted.
- 3.2 **Absorption.** A limited human study suggested that most of a low oral dose of BaP was systemically absorbed, in that no BaP was detected in the faeces of the eight volunteers who each ingested 9 μg in a portion of meat (Hecht *et al*, 1979). There was approximately 30% absorption through the gastrointestinal tract of rats when a low dose of BaP was administered by a tube directly into the duodenum, and a slightly higher absorption when a high dose was given in the diet or by gavage (Chang, 1943). High oral doses, 50–150 mg kg^{-1} bw (milligrams per kilogram body weight), were said to be “readily absorbed” from the gastrointestinal tract of rats (Rees *et al*, 1971; WHO, 1991a).
- 3.3 BaP in air is likely to be adsorbed onto particles (DETR, 1999). The time taken for 50% clearance of BaP from the lungs of hamsters varied from 2 h if the BaP was on ferric oxide (of 0.5–20 μm) up to 60 h if it was adsorbed on carbon particles (of 15–30 μm) (Henry and Kaufman, 1973). BaP administered as an aerosol was cleared from the lungs of rats by a biphasic process, with an initial rapid phase (tracheal clearance) followed by a much slower second phase (alveolar clearance) (Mitchell, 1982). Investigations of the pulmonary absorption of PAHs are complicated by the existence of mucociliary clearance whereby PAHs adsorbed onto inhaled particles are swept back up the pulmonary tree and swallowed (WHO, 1998a).
- 3.4 Almost all of a dose of BaP applied to the skin of mice appeared in the faeces within two weeks (Heidelberger and Weiss, 1951), suggesting extensive dermal absorption. Skin absorption in rats, monkeys and guinea pigs was described as “rapid and high” (ATSDR, 1995). The absorption of BaP from soil into human skin has been demonstrated *in vitro* (Wester *et al*, 1990).
- 3.5 **Distribution.** After oral administration of low daily doses of radiolabelled BaP to rats, the radioactivity persisted in the kidney and testes (Yamazaki and Kakiuchi, 1989).
- 3.6 Following inhalation of radiolabelled BaP aerosols in rats, the highest levels of radioactivity 1 h after treatment were present in the stomach and small intestine, and, as these declined, in the large intestine and caecum (Mitchell, 1982).
- 3.7 **Metabolism.** BaP is metabolised mainly but not exclusively in the liver (by cytochrome P450 enzymes) to a range of epoxides (1,2-, 2,3-, 4,5-, 7,8- and 9,10- oxides of BaP). These may spontaneously rearrange to phenols, be hydrated to dihydrodiols catalysed by epoxide

hydrolase, or react covalently with glutathione. The same family of enzymes may further oxidise the dihydrodiols to a range of phenol derivatives and diol epoxides. BaP is also metabolised to 6-hydroxy-BaP, and hence to a number of quinones (WHO, 1998a). The metabolites produced by different human tissues are qualitatively similar, and there seem to be no marked differences in BaP metabolism between species (WHO, 1998a). In rats given a low dose of BaP by stomach tube, about 10% of the absorbed dose escaped first-pass metabolism by the liver.

- 3.8 **Excretion.** Most BaP metabolites are excreted in the urine and faeces. The core of the molecule remains intact and so very little of an administered dose appears as carbon dioxide in the expired air (WHO, 1998a). There is evidence of fairly extensive enterohepatic circulation in rats and guinea pigs (Bowes and Renwick, 1986; Chipman *et al*, 1981; Weyand and Bevan, 1986).
- 3.9 Almost all of the BaP applied to the skin of mice was excreted in the faeces (Heidelberger and Weiss, 1951).
- 3.10 **Acute toxicity.** BaP was probably of fairly low acute oral toxicity in the mouse, with an LD₅₀ value in excess of 1600 mg kg⁻¹ bw (Awogi and Sato, 1989). By intraperitoneal injection, the LD₅₀ in mice was 232 mg kg⁻¹ bw (Salamone, 1981).
- 3.11 **Repeated toxicity.** Whilst there is a large epidemiological literature on workforces exposed to complex mixtures of PAHs, it is not possible with any confidence to disentangle the contribution of individual PAHs to the adverse effects that clearly result, which include chronic dermatitis, breathing problems, chest pains, chest and throat irritation, non-tumour pathology in the lung, cancer of the skin and lung and a depressed immune system (ATSDR, 1995).
- 3.12 Adverse skin reactions have resulted from the repeated local application of 1% BaP solutions to patients with pre-existing skin conditions (ATSDR, 1995).
- 3.13 Oral administration of BaP reduced the survival of mice at doses of 120 mg kg⁻¹ bw day⁻¹ (milligrams per kilogram body weight per day), probably due to major haematological effects. Liver enzyme induction and damage and effects on kidney enzyme activity have also been reported at doses of this order (ATSDR, 1995; Robinson *et al*, 1975). There were often marked strain differences in the extent of the toxicity (Robinson *et al*, 1975).
- 3.14 No overt signs of toxicity or pathology of the nose, lung and kidney were present in rats exposed 2 h day⁻¹, 5 day week⁻¹ for four weeks to 7.7 mg m⁻³ of a BaP aerosol (Wolff *et al*, 1989).
- 3.15 Other animal studies indicate that BaP is able to induce non-tumour effects on the skin, respiratory and gastrointestinal tract, liver, uterus, ovaries and testes, and can influence the arteriosclerotic process and the immune system. The studies generally involve injection of the test material, often only at high doses, and the results are therefore of no real value in defining the dose–response of the toxicity likely to arise from either oral or inhalation exposure to BaP (ATSDR, 1995; Meiss *et al*, 1982).

- 3.16 **Reproductive toxicity.** The administration of a maternally toxic dose of 120 mg kg⁻¹ bw in the diet on gestation days 2–10 produced foetal malformations. Lower doses were not tested. The effect was influenced by the genetic constitution of the mice (Legraverend *et al*, 1984). In another mouse strain, total foetal death was seen in a large proportion of the animals given doses of 40 or 160 mg kg⁻¹ bw by gavage on days 7–16 of gestation. A reduced fertility was also seen in the lowest tested dose of 10 mg kg⁻¹ bw day⁻¹ (MacKenzie and Angevine, 1981).
- 3.17 In rats, the administration by gavage of 60 mg kg⁻¹ bw on day 19 of gestation induced liver enzyme activity in the offspring (Welch *et al*, 1972).
- 3.18 High intraperitoneal doses (100–150 mg kg⁻¹ bw) to pregnant mice suppressed the immune system of the offspring (Urso and Gengozian, 1980).
- 3.19 **Sensitisation.** In guinea pigs, two dermal applications of 0.001% BaP produced evidence of sensitising potential (ATSDR, 1995).

4 Carcinogenicity and Genotoxicity

- 4.1 There is an extensive literature on the epidemiology of workforces exposed to complex mixtures of PAHs in, for example, aluminium production (Armstrong *et al*, 1994) and coke production (Redmond, 1976; Redmond, 1983), and in those handling coal tar, coal tar pitches and soot (IARC, 1987). This conclusively demonstrates an elevated incidence of lung tumours on inhalation and of skin tumours from skin contact (ATSDR, 1995; IARC, 1987). It is not possible, however, to assess with confidence the contribution of individual PAHs to the observed cancer burden (USEPA, 2001).
- 4.2 The overall conclusion of an IARC Working Group in 1987 was that BaP was “probably carcinogenic to humans” (Group 2A) (IARC, 1987). There were no adequate human data, but “sufficient” evidence of carcinogenicity in experimental animals (IARC, 1983). In 1992, the USEPA judged BaP to be a “probable human carcinogen” (B2) on the basis of the “sufficient” evidence of its carcinogenicity in laboratory animals and supporting data from numerous genotoxicity assays (USEPA, 2001).
- 4.3 Forestomach tumours were induced in mice given BaP in the diet (Culp *et al*, 1996; Neal and Rigdon, 1967; Weyand *et al*, 1995). No forestomach tumours were present in an untreated control group of 289 mice or groups given 1, 10 or 30 ppm BaP. There were single forestomach tumours at 20 and 40 ppm (in groups of 23 and 40 respectively), a 10% incidence at 45 ppm and then a rapidly increasing incidence in the higher-dose groups. The treatment time varied from 98 to 197 days (Neal and Rigdon, 1967). In a two-year study in mice, the forestomach tumours developed even at the lowest tested dietary concentration of 5 ppm ($18.5 \mu\text{g day}^{-1}$) (about $750 \mu\text{g kg}^{-1} \text{bw day}^{-1}$) (Culp *et al*, 1996).
- 4.4 Lung tumours and leukaemias have been reported in mice in dietary (Rigdon and Neal, 1969; Weyand *et al*, 1995) and gavage (Nebert and Jensen, 1979; Wattenberg and Leong, 1970) studies. Oesophageal tumours developed in mice given BaP by gavage (Horie *et al*, 1965).
- 4.5 In rats treated orally for life, in either dietary or gavage studies, there was a statistically significantly higher combined incidence of tumours of the forestomach, oesophagus and larynx in all but one of the five groups given BaP than in the respective controls. The tested annual doses ranged from 6 up to $39 \text{mg kg}^{-1} \text{bw}$. In the dietary study the tumour yield, which was the same in the control animals as in those receiving an annual dose of $6 \text{mg kg}^{-1} \text{bw}$, was clearly raised at $39 \text{mg kg}^{-1} \text{bw}$ (Brune *et al*, 1981). In the gavage study, the increase was obvious at $18 \text{mg kg}^{-1} \text{bw}$ (Brune *et al*, 1981).
- 4.6 The administration by gavage, of $100 \text{mg kg}^{-1} \text{bw}$ on a single occasion (Huggins and Yang, 1962) or eight doses of around $20 \text{mg kg}^{-1} \text{bw}$, resulted in a very marked increase in mammary tumours in rats (McCormick *et al*, 1981).
- 4.7 Limited studies in hamsters found that orally administered BaP produced a range of tumours in the gastrointestinal tract (Chu and Malmgren, 1965; Dontenwill and Mohr, 1962).

- 4.8 Increases in the incidence of tumours of the upper respiratory tract and the upper digestive tract (including oesophagus, pharynx and forestomach) were seen in male hamsters exposed 3–4.5 h day⁻¹ for 109 weeks to 9.5 or 46.5 mg m⁻³ of BaP particles (99% between 0.2 and 0.54 µm in diameter). No treatment-related tumours developed in the 27 males exposed to 2.2 mg m⁻³ (Thyssen *et al*, 1981). Intratracheal administration to hamsters and rats did produce lung tumours (Davis *et al*, 1975; Ishinishi *et al*, 1976; Pott *et al*, 1987; WHO, 1998a).
- 4.9 A large number of skin painting studies in mice have shown BaP to be a potent local carcinogen (WHO, 1998a). Doses of around 2 µg per mouse (about 100 µg kg⁻¹ bw per application) given two or three times weekly for life (or for considerably shorter periods along with promoters) (Habs *et al*, 1980, 1984; Rice *et al*, 1988, 1990), or concentrations of as low as 0.001% (Wynder and Hoffmann, 1959), were able to induce skin tumours. In a four-generation skin painting study in mice, a higher yield of skin tumours was seen in the later treated generations (Andrianova, 1971). Dermal application has also produced skin tumours in rats, rabbits and guinea pigs (USEPA, 2001; WHO, 1998b).
- 4.10 Tumours are not only induced at the site of initial contact with BaP. Transplacental carcinogenesis, where the treatment of the pregnant female results in tumours of the offspring, has been reported in mice and rabbits (Beniashvili, 1978; Bulay and Wattenberg, 1971; Nikonava, 1977). In addition, liver and lung tumours have developed in newborn mice given intraperitoneal or subcutaneous injections of BaP (ATSDR, 1995).
- 4.11 BaP is mutagenic in *Salmonella typhimurium* (Ames test) in the presence of liver activation. In mammalian cells in culture, it induces chromosomal damage, and increases the incidence of sister chromatid exchange (WHO, 1998a). Evidence of genotoxic potential has also been seen in a wide range of *in vivo* studies in both somatic and germ cells (dominant lethal assay and cytogenetics in spermatogonial cells) (ATSDR, 1995; WHO, 1998a). DNA adducts have been detected in various tissues in rats and mice (WHO, 1991a), and in the peripheral lymphocytes and bronchial cells of humans (WHO, 1998a).

5 Derivation of Index Doses

The recommendations of JECFA

- 5.1 At a 1990 meeting, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) concluded that the most significant toxicological effect of BaP was its carcinogenicity, and that, as BaP is only one member of a class of more than 100 compounds, the PAHs should be considered as a class. “The Committee was unable to establish a tolerable intake for BaP, based on the available data.” They noted that there was a large difference between the estimated human intake and the doses that induce tumours in animals, and suggested that any effects on human health are likely to be small. “The considerable uncertainties in risk estimation require that efforts should be made to minimise human exposure to BaP as far as is practicable” (WHO, 1991a,b).

The WHO guidelines for drinking-water quality

- 5.2 A WHO Task Group in 1992 noted that “adequate data upon which to base a quantitative assessment of the carcinogenicity of ingested PAHs are available only for BaP” (WHO, 1993). The study of Neal and Rigdon (1967) served as a basis for the derivation of a guideline value. The dose–response of the forestomach tumours that developed in the mice given BaP in the diet was analysed by a mathematical model (two-stage birth–death mutation model) that could accommodate the variable exposure and sacrifice patterns of the complex experimental protocol. On the premise that humans would display the same quantitative sensitivity to the cancer potency (cancers per unit dose) of BaP as did the mouse, it was estimated that the concentrations of BaP in drinking water corresponding to excess lifetime cancer risk of 10^{-4} , 10^{-5} and 10^{-6} would be 7, 0.7 and $0.07 \mu\text{g L}^{-1}$ respectively (WHO, 1996). The recommended guideline value for BaP in drinking water was set at $0.7 \mu\text{g L}^{-1}$ (WHO, 1993).
- 5.3 The finalisation of the WHO Environmental Health Criteria monograph on PAHs in 1995 (WHO, 1998a) encouraged the re-evaluation of acceptable limits of PAHs in drinking water (WHO, 1998b). “Nearly identical results” of additional limited mouse studies (Culp *et al*, 1996; Weyand *et al*, 1995) on BaP were considered by the Working Group to give support for the validity of the Neal and Rigdon study (and thus presumably for the risk estimations based on the data it generated), and the guideline value for BaP of $0.7 \mu\text{g L}^{-1}$ was therefore confirmed.

The recommendations of the Expert Panel on Air Quality Standards

- 5.4 A study of the cancer mortality of workers at an aluminium smelter in Canada (Armstrong *et al*, 1994) provided the basis of the UK air quality standard for PAHs. The observed large excess of lung cancer was assumed to have been the result of the presence of PAHs in the workroom air. The working lifetime (40-year) exposure producing an approximate 50%

increase in cancer risk was estimated to have been equivalent to 0.25–2.5 $\mu\text{g m}^{-3}$ of BaP as a marker of total PAH exposure.

- 5.5 The response at the lower end of this range (0.25 $\mu\text{g m}^{-3}$) was considered to be a “lowest observed adverse effect” level (LOAEL), to which three uncertainty factors of 10 – one to convert a LOAEL to a “no observed adverse effect” level (NOAEL), one to take account of the difference between an occupational exposure (of 8 h day⁻¹, 5 day week⁻¹ for up to 40 years) and an entire-life continuous population exposure, and one to accommodate inter-individual variations in response – were applied. This generated a standard of 0.25 ng m⁻³ of BaP as a marker for the total mixture of PAHs. This figure was considered “to reduce any risk to the population of the United Kingdom from exposure to PAHs to one which the Panel believes would be so small as to be undetectable” (DETR, 1999). The Expert Panel expressed some concern over the adequacy of BaP as a reliable marker of total PAH exposure and called for more data to justify its validity.

The WHO air quality guidelines for Europe

- 5.6 In commenting on the difficulty of undertaking risk assessments on individual PAHs, a WHO Working Group has noted that, even for BaP, the best-studied compound of this class, the process was “hampered by the poor quality of the data sets available” (WHO, 2000). At present air quality guidelines are therefore only available for PAHs as an overall class. These are based on the cancer pattern seen in workers exposed to coke-oven emissions (Redmond, 1976), a complex mixture of PAHs, but are expressed in terms of BaP as an indicator of the total PAH burden (WHO, 1987).
- 5.7 Using a linearised multi-stage model, the most plausible upper-bound individual lifetime risk estimate associated with a continuous exposure to 1 $\mu\text{g m}^{-3}$ of benzene-soluble compounds of coke-oven emissions was estimated to be about 6.2×10^{-4} . As the reported concentration of BaP in the benzene-soluble fraction was 0.71%, this was equivalent to a lifetime risk of respiratory cancer of 8.7×10^{-5} per ng BaP m⁻³ (with the BaP being “an indicator of general PAH mixtures from emissions of coke oven and similar combustion processes in urban air”). The corresponding concentrations of this characteristic PAH mix producing excess lifetime cancer risks of 10^{-4} , 10^{-5} and 10^{-6} were 1.2, 0.12 and 0.012 ng BaP m⁻³ respectively (WHO, 2000).
- 5.8 The WHO Working Group was reassured that the figure of 8.7×10^{-5} per ng BaP m⁻³ was of the “same order of magnitude” as the 2×10^{-5} per ng BaP m⁻³ derived from applying a linearised multi-stage model to the lung tumour rates seen in a rat inhalation study of coal tar/pitch condensation aerosols (Heinrich *et al.*, 1994; WHO, 2000). The PAH composition of the emissions from heated pitch are said to be comparable to those from coke ovens (WHO, 1987).

The recommendations of the USEPA

- 5.9 The observation of forestomach tumours in mice, and forestomach, oesophagus and larynx tumours (combined) in rats, in studies in which BaP was administered in the diet (Neal and Rigdon, 1967; Brune *et al*, 1981) allowed the USEPA in 1992 to estimate the oral cancer risk of BaP (USEPA, 2001). The risk estimate was based on a geometric mean of four slope factors obtained by differing modelling procedures. Data were also used on the spontaneous incidence of forestomach tumour type seen in another mouse study (Rabstein *et al*, 1973).
- 5.10 An overall slope factor of 7.3×10^{-3} per $\mu\text{g BaP kg}^{-1} \text{ bw day}^{-1}$ was generated. Assuming humans and rodents have the same quantitative susceptibility to BaP's cancer action, it would mean that the ingestion of $1 \mu\text{g BaP kg}^{-1} \text{ bw day}^{-1}$ would pose a lifetime cancer risk of 7.3×10^{-3} . The USEPA noted that a lifetime cancer risk of 10^{-4} was associated with a concentration of BaP in drinking water of 50 ng L^{-1} .

The recommendations of the ATSDR

- 5.11 The ATSDR has attempted to derive minimum risk levels (MRLs) (an estimate of daily exposure that is likely to be without an appreciable risk of non-carcinogenic adverse effects) for BaP and 16 other PAHs (ATSDR, 1995).
- 5.12 No chronic oral MRLs were possible because "there were no adequate human or animal dose-response data available that identify threshold levels for appropriate non-cancer health effects".
- 5.13 No inhalation MRLs could be derived for any of the PAHs because there were insufficient dose-response data on non-cancer health effects.

Conclusions

- 5.14 Both the WHO and the USEPA have attempted to estimate the human cancer risks of ingested BaP by the low-dose extrapolation of the dose-response curves of the forestomach tumours seen in dietary studies in rodents. The mathematical model applied by the WHO Task Group to the mouse cancer data of Neal and Rigdon was slightly unusual, but was chosen because it was more capable of handling the complicated experimental protocol, with its varying periods of treatment and sacrifice. On the assumption that humans and the mouse exhibit the same quantitative susceptibility to BaP's cancer potency, a conventional default in the absence of cancer data in humans exposed orally, the model indicated that a concentration of 700 ng L^{-1} of BaP in drinking water would pose a lifetime cancer risk to humans of 10^{-5} . A later WHO Working Group noted that the results of two other mouse studies provided additional support for this guideline value of 700 ng L^{-1} .
- 5.15 As well as the mouse data of Neal and Rigdon, the USEPA also used the findings of the rat study of Brune *et al* (1981). The dose-response of the forestomach tumours in the mice, and combined forestomach, larynx and oesophagus tumours seen in the rats, were subjected to a number of mathematical models and the results were averaged (a geometric mean was

- calculated). This generated an estimate of the human cancer risk from oral exposure that was higher than that of the WHO; a drinking water concentration of 50 ng BaP L⁻¹ was estimated to produce a lifetime cancer risk of 10⁻⁵. The low-dose extrapolation of cancer data from laboratory animal studies is not an exact science, and its main value is in providing worst-case approximate orders of magnitude of risk. In this context, the WHO and USEPA values are therefore in fair agreement.
- 5.16 The WHO guideline value for drinking water is adopted here as the basis for the health criteria value for oral intake of BaP from soil. BaP is a genotoxic carcinogen and the objective of the WHO guideline value is to ensure that the lifetime cancer risk of consuming water of this quality will be of no practical significance. In the present context it should therefore be viewed as the basis of an Index Dose and should be accompanied by measures to keep exposures as low as reasonably practicable. At the WHO guideline value of 700 ng L⁻¹, a 70 kg human consuming 2 L day⁻¹ of water would be exposed to 1.4 µg BaP day⁻¹ or 20 ng kg⁻¹ bw day⁻¹ and this is the recommended oral Index Dose.
- 5.17 Both WHO and the UK Expert Panel on Air Quality Standards have evaluated the risk of lung cancer from occupational exposure to inhaled PAHs, expressed in terms of BaP concentrations as an index of the total PAH burden. The UK Expert Panel used data from a study of workers at a Canadian aluminium smelter, whereas the WHO favoured a study of workers exposed to coke-oven emissions.
- 5.18 The UK Expert Panel applied a number of safety factors to an effect level for cancer to derive a figure of 0.25 ng BaP m⁻³. This was the atmospheric concentration considered to pose a cancer risk that was so small as to be “undetectable”. The WHO Working Group applied a mathematical modelling technique for the extrapolation of the dose–response of a genotoxic carcinogen that would be assumed not to exhibit a dose threshold. The WHO analysis indicated that the concentration of PAH mixture represented by the BaP standard derived by the UK Expert Panel would be associated with a lifetime lung cancer risk of about 4 × 10⁻⁵. The estimated risk from BaP alone at this concentration would be lower. The UK Expert Panel, using cancer data on seven of the established carcinogenic PAHs in the workroom air of the Canadian smelter, estimated that BaP contributed 37–49% of the total PAH cancer activity. With this in mind, the 0.25 ng m⁻³ figure of the UK Panel is recommended here.
- 5.19 Because the health effect being considered is genotoxic carcinogenesis, the 0.25 ng m⁻³ value is best described as an Index Dose, and would also be associated with an expectation that exposures would be kept as low as reasonably practicable. A 70 kg adult inhales about 20 m³ of air daily, and 0.25 ng m⁻³ of BaP will therefore equate to an inhalation Index Dose of 0.07 ng BaP kg⁻¹ bw day⁻¹.
- 5.20 No authoritative UK or international group appears to have published any quantitative assessment of the health risks posed by dermal exposure to BaP. It should be kept in mind that BaP is a multi-species genotoxic skin carcinogen. In the mouse, it has exhibited an extremely high cancer potency, with the treatment-related induction of tumours occurring at repeated skin applications in the order of 100 µg kg⁻¹ bw or concentrations as low as 0.001%.

6 The Intake of BaP from Food, Water and Air

- 6.1 Analyses of UK total-diet samples (collected in 1979) for BaP and several other PAHs have been reported by the Ministry of Agriculture, Fisheries and Food (MAFF) (Dennis *et al*, 1983). In the calculation of the daily dietary intakes, the investigators took a concentration (of a PAH in any foodstuff) below the detection limit as zero. The intake of BaP was estimated to be $0.25 \mu\text{g day}^{-1}$.
- 6.2 A more recent study – a market basket survey – has been carried out in the Netherlands (de Vos *et al*, 1990). Both an upper-bound mean and a lower-bound mean daily intake (corresponding to taking values below the detection limit as equal to the limit and as zero, respectively) are reported. The respective figures for BaP were 0.29 and $0.12 \mu\text{g day}^{-1}$.
- 6.3 The group from MAFF have investigated the factors likely to influence the PAH content of those foodstuffs making the major contribution to the total PAH intake, namely cereals and oils/fats (Dennis *et al*, 1991). They found that, in general, the PAH concentrations in cereals and in some of the oils and fats were lower than those reported earlier (in Dennis *et al*, 1983). Although they do not give figures for the total mean daily intakes of the PAH compounds in the later report, it is possible to make some estimates from their data. The intakes from cereals were typically a factor of 2 lower, and those from fats/oils a factor of 2–3 lower, than in the 1983 report.
- 6.4 One drawback of a total-diet study is that it does not give the range of intakes of the contaminant in the population group studied. However, in their 1983 paper, Dennis *et al* do give means and ranges for the concentrations found in individual foodstuffs. For BaP in oils and fats there was a factor of about 20 between the highest and lowest values, and a factor of about 2.5 between the mean and the highest value. A more direct indication of the range of intakes can be found in a study of ten families in New Jersey who were monitored for two weeks (Lioy *et al*, 1988). Food samples were obtained daily from each family meal and analysed for BaP. The overall mean daily intake was found to be $0.09 \mu\text{g}$, a figure not markedly different from those found in the UK and Dutch surveys mentioned above. The individual intakes over the two-week period ranged from about 0.01 to $0.4 \mu\text{g day}^{-1}$ – that is, there was a factor of 40 between the highest and lowest values, and a factor of about 5 between the highest and the mean values.
- 6.5 There has been some concern about the possibility of very high PAH concentrations in smoked foods. In the UK, relevant measurements have been reported by McGill *et al* (1981), who investigated the PAH concentrations in samples of smoked fish, bacon and cheese. Although higher concentrations were generally found in the smoked foodstuffs compared with their unsmoked counterparts (typically $\times 2$ for bacon and meat and $\times 8$ for fish), it was found that the smoked foods made only a minor contribution to the total PAH intake. Thus, for BaP, the mean daily intake from smoked fish and smoked bacon combined was estimated to be about $0.004 \mu\text{g}$.

- 6.6 Average PAH concentrations in air at three urban sites have been reported by the Quality of Urban Air Review Group (QUARG, 1993). A programme of PAH measurements at a number of urban sites has also been carried out (Clayton *et al*, 1992). Typical mean annual concentrations of BaP are 1.3 ng m^{-3} .
- 6.7 Though BaP is regularly monitored in UK drinking water for regulatory purposes, this information is not generally published. The WHO consider that the main source of PAHs is food, with drinking water contributing only minor amounts (WHO, 1993, 1996). There has been a statutory limit of 10 ng L^{-1} for BaP in drinking water since 1989.

7 Other Sources of BaP

- 7.1 The average BaP content in the mainstream smoke of a “low-tar” cigarette is about $0.01 \mu\text{g}$ (WHO, 1987). This would result in a daily intake of $0.2 \mu\text{g}$ for a person who smokes 20 cigarettes per day.

8 Conclusions

- 8.1 The Index Doses derived from oral and inhalation studies (that is, ID_{oral} and ID_{inh}) of BaP for a 70 kg adult are summarised in Table 8.1.

Table 8.1 Index Doses derived from oral and inhalation studies

ID_{oral} ($\mu\text{g kg}^{-1} \text{ bw day}^{-1}$)	ID_{inh} ($\mu\text{g kg}^{-1} \text{ bw day}^{-1}$)
0.02	0.07×10^{-3}

- 8.2 The Index Dose represents a dose that poses a minimal risk level from possible exposure from a particular source, with the additional requirement that exposure needs to be reduced to as low a level as reasonably practicable (DEFRA and Environment Agency, 2002a). Therefore, background exposure to BaP is not considered, and the Index Dose itself is the toxicological assessment parameter used for deriving Soil Guideline Values for BaP (for details see SGV 2, DEFRA and Environment Agency, in prep).
- 8.3 No authoritative assessments of the health risks posed by dermal exposure to BaP were identified. BaP is a multi-species genotoxic skin carcinogen, and has demonstrated a very high cancer potency in the mouse.
- 8.4 These conclusions are for BaP only. However, BaP should not be looked at in isolation. A review is currently under way to derive health criteria for other toxicologically relevant PAHs and Soil Guideline Values will be derived for these in the near future.

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