Substance name: Anthracene
EC number: 204-371-1
CAS number: 120-12-7

MEMBER STATE COMMITTEE

SUPPORT DOCUMENT FOR IDENTIFICATION OF ANTHRACENE AS A SUBSTANCE OF VERY HIGH CONCERN

Adopted on 8 October 2008

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TABLES

Substance Name: Anthracene

EC Number: 204-371-1

CAS number: 120-12-7

- *The substance is identified as a PBT substance according to Article 57 (d) of Regulation (EC) No 1907/2006 (REACH).*

Summary of the evaluation:

In accordance with the criteria defined in Art. 57(d) anthracene is a PBT substance.

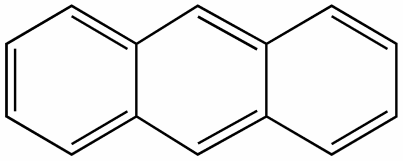
Anthracene is very persistent in sediment and soil and therefore fulfils both the P-criterion and the vP-criterion. With experimentally determined BCFs in the range of 420 to 6,000 for the parent compound the B-criterion is met. Aquatic toxicity assessment gives NOECs in the range of 0.0012 mg/L (fish, algae) to 0.002 mg/L (daphnia). Thereby, the T-criterion is also fulfilled.

The PBT-status of anthracene was confirmed by a CEFIC re-evaluation submitted to the European Commission in connection with the discussions on the revision of REACH Annex XIII. In addition to that it needs to be mentioned that anthracene was selected as a priority hazardous substances in the framework of the European Water Framework Directive due to its persistent, bioaccumulative and toxic properties, and findings in freshwater and marine ecosystems.

JUSTIFICATION

1 IDENTITY OF THE SUBSTANCE AND PHYSICAL AND CHEMICAL PROPERTIES

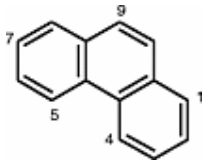
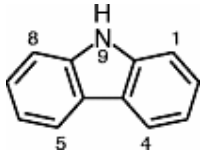
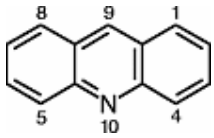
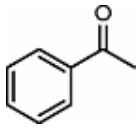
1.1 Name and other identifiers of the substance

Name:	Anthracene
EC Number:	204-371-1
CAS Number:	120-12-7
IUPAC Name:	Anthracene
Molecular Formula:	C14H10
Structural Formula:	
Molecular Weight:	178.24
Synonyms:	Paranaphtalene, p-naphtalene, green oil, tetra olive, anthracene

1.2 Composition of the substance

Technical grade anthracene has a purity of approximately 97%. The main impurities are displayed in Table 1.

Table 1: Main impurities of anthracene

Impurity	Content [%]	CAS no.	EC no.	Molecular formula
Phenanthrene 	1.0	85-01-8	201-581-5	C14H10
Carbazole 	1.0	86-74-8	201-696-0	C12H9N
Naphthothiophene	0.4			
Dibenzo[b,c]thiophene	0.3			
Acridine 	0.2	260-94-6	205-971-6	C13H9N
Acetophenone* 	0.4	98-86-2	202-708-7	C8H8O

* According to information of an anthracene-producer, an acetophenone-free anthracene production is possible.

1.3 Physico-chemical properties

Table 2: Summary of physico-chemical properties (For details and references see European Commission (2007a))

REACH ref. Annex, §	Property	Value	Comments
VII, 7.1	Physical state at 20 C and 101.3 Kpa	Colorless crystalline solid with violet fluoresence	
VII, 7.2	Melting / freezing point	216.4 0C	
VII, 7.3	Boiling point	342 ^{0}C	
VII, 7.5	Vapour pressure	9.4 * 10^{-4} Pa	at 25 ^{0}C
VII, 7.7	Water solubility	0.047 mg l^{-1}	at 25 ^{0}C
VII, 7.8	Partition coefficient n-octanol/water (log value)	4.68	
	Dissociation constant	-	

2 CLASSIFICATION AND LABELLING

Proposed classification (European Commission, 2007a)[1]:

CLASSIFICATION

Xi; R38	Irritating to skin
N; R50-53	Very toxic to aquatic organisms. May cause long-term adverse effects in the aquatic environment

LABELLING

Xi; N

R: 38-50/53

S: 37-60-61

[1] "In November 2005 the human health (HH) Classification and Labelling Group (TC C&L) in the context of directive 67/548/EEC agreed that the rapporteur Classification proposal Xi; R38 should not be applied to reflect photo irritancy." (European Commission, 2008). The discussion about the classification and labelling of anthracene is still open. (Anthracene was not included into the 30th or 31th ATP.)

3 ENVIRONMENTAL FATE PROPERTIES

3.1 Degradation

3.1.1 Stability

Once dissipated into air, anthracene undergoes indirect photo-oxidation induced by OH^- and NO_3 - radicals and O_3 in the atmosphere. Half-life of ca. 3.4 hours (at 52 ^oC) has been derived in the risk assessment of anthracene using the default 5 x 10^5 OH^- molecules cm^{-3} and the experimentally derived rate constant of 1.12 x 10^{-10} cm^3/(molecule*sec) at 52 ^oC (European Commission, 2007a). Using EpiSuite, a half-life for atmospheric degradation of 9.63 h is calculated for 25 ^oC (rate constant of 40 x $10^{-12}$$cm^3$/(molecule*sec)). Transformation rate in particle phase is expected to be lower. Particle phase transformation is, however, not assumed to be of relevance for the overall atmospheric lifetime, because only up to 3 % of atmospheric anthracene has been observed to appear in particle phase (European Commission, 2007b).

In aqueous systems, anthracene is hydrolytically stable. However photochemical transformation in water and sediments has been observed in laboratory studies and “in situ”. Half-lives for primary photodegradation in water have been reported in the range of 20 minutes to 125 hours depending on the experimental conditions used. The highest value corresponds to photolysis in winter conditions. Anthraquinone has been identified as the main abiotic degradation product of anthracene (European Commission, 2007a).

Environmentally relevant exposure occurs in the whole water column, in sediment and soil due to its partitioning behaviour. Photodegradation of anthracene can be expected to be a relevant removal pathway in the environment only in very shallow clear waters and in the first few centimetres of the water column. Therefore aquatic photodegradation is not considered to have relevant impact on the overall persistency of anthracene in the environment.

3.1.2 Biodegradation

3.1.2.1 Screening tests

Mackay et al. (1992) allocated anthracene to persistency class 4 for water and class 7 for sediment corresponding to half-lives of 13-42 days (water) and 420-1250 days (sediment). These half-lives are used in the risk assessments of anthracene and coal tar pitch, high temperature (European Commission, 2007a, 2007b). Lower half-lives have been reported in the literature with respect to the disappearance of anthracene from the culture medium (either by volatilisation, adsorption, biotransformation or uptake by organisms). However, it needs to be stressed that these studies only consider dissipation and not mere degradation of anthracene (e.g. mineralisation).

Degradation of 1.9 % of the initial anthracene concentration measured as BOD was observed in a 14 day ready biodegradability test (MITI I, OECD 301C) using 100 mg l^{-1} anthracene and 30 mg l^{-1} sludge (CITI, 1992). Sludge employed in the test was likely to be predominantly domestic. According to the MITI test, which is suitable for substances with low water solubility, anthracene is not readily biodegradable.

Significant degradation due to gradual adaptation was reported for anthracene in a biodegradation test by Tabak et al. (1981). A static screening procedure based on BOD monitoring was used. The inoculum used was settled domestic sewage sludge. The cultures were incubated for seven days in

the dark at 25 ºC. A subculture of the inoculum was taken after 7 days and incubated for a further 7 days. A total of three subcultures were taken, i.e. at the end of the incubation period of the third subculture the inoculum had been adapted for 28 days. Test concentrations of 5 and 10 mg l^{-1} were introduced into the flasks using dispersant. Degradation in the range of 26 % (at day 7) up to 92 % (at day 28) resulted. This study demonstrates that waste water treatment plant microorganisms can adapt to biodegrade anthracene but the rate of biodegradation cannot be judged on the basis of the study.

3.1.2.2 Simulation tests

The degradation of PAHs in sediment was studied by Gardner et al. (1979). Sediment has been spiked with crude oil enriched with selected PAHs. Three different sediment types were used: fine sand (0.125 to 0.25 mm particle size), medium sand (0.25 to 0.5 mm) and marsh sediment (61 % sand (0.062 to 2 mm) 12 % silt (0.002 to 0.062 mm), and 26 % clay (< 0.002 mm particle size). Each tray ($0.1m^2$) contained 2 l dry volume of sediment. The incubation temperature was 20 ± 2°C. Estuarine water (salinity 25 ‰) and 5 ml of the crude oil enriched with 0.1 g of e.g. anthracene was added to each tray. The experiment lasted for 31 weeks.

The initial concentrations of anthracene were highest in the marsh sediment (40 µg/g dry sediment) and lowest in the medium sand (10.3 µg/g dry sediment). The authors reported that between 2.0 % (fine sand) and 3.2 % (medium sediment) of anthracene was removed every week. In general, PAH degradation was higher in surface than in subsurface layers of sediment. The authors concluded that slow removal of PAHs from marsh sediments may have been caused by factors making the oils unavailable to microorganisms (e.g. adsorption to clay minerals or sediment organic material).

The study provided by Gardner et al (1979) simulates an oil spill to a water body and is valid with restrictions since no mass balance is available and possible effects of adsorption or volatilisation of the PAHs have not been considered. Although no half-lives have been calculated, the results indicate that anthracene is persistent in lower sediment layers.

Lee & Ryan (1983) studied biodegradation of ^{14}C-labelled anthracene in water and sediment measuring the evolution of $^{14}CO_2$ and degradation products. Water and sediment were collected for the study from one heavily with oil contaminated estuary in Charleston, SC, and from a “cleaner” estuary in Savannah, GA, in the United States. The sediment samples were taken from the upper 1 cm where microbial degradation of hydrocarbon is highest.

For the biodegradation test in water, ^{14}C-labelled anthracene was added to 100 ml samples in 250 ml flasks in a concentration of 25 µg l^{-1}. For the test in sediment, ^{14}C-labelled anthracene was added to a sediment-seawater slurry consisting of 1 g of sediment and 50 ml of seawater in 125 ml bottles. Test concentration was 2.5 mg kg^{-1} (no information whether dwt or wwt). Triplicate samples were tested. Incubation temperature was 27ºC for the samples from Charleston and 28 C for the samples from Savannah. With regard to the biodegradation test in water, the authors observed little, if any, degradation of anthracene, whereas for the sediment test mineralisation half-lives of 210 days (the “cleaner” Savannah sediment) and 57 days (the contaminated Charleston sediment) were extrapolated (Lee & Ryan 1983).

A similar test was performed with sediment samples from Narragansett Bay, RI, which were incubated in mesocosms (Lee & Ryan 1983). The study resulted in dissipation half-lives of 95, 99, and 141 days for test concentrations of 1, 2.5 and 5.0 mg anthracene kg^{-1}, respectively at temperatures of 18 °C. Those mesocosm sediments which were pre-adapted by fuel oil addition, showed degradation half-lives of 5, 6, and 7 days, respectively, at concentrations of 1, 2.5 and 5.0

mg kg^{-1}. According to the authors, biodegradation was at negligible or low level in mesocosm water samples.

It must be noted that the test conditions of Lee & Ryan (1983) did not resemble conditions required at the present for simulation tests. The batch size was small and the water-sediment batches were agitated. Moreover the sediment samples where taken from the upper sediment layer, where degradation is higher than in lower layers. Hence, the test system produced enhanced biodegradation rates compared to environmentally relevant conditions. In addition, the degree of pre-adaptation of the samples cannot be judged, because the characteristics of the sites were not reported in detail.

Bauer et al. (1985) conducted a trial sequence for testing the impact of temperature, oxygen, NO_3^-, glucose and pre-adaptation on the biodegradation of anthracene. The tests were conducted using sediment-water slurries (1:2 wwt/vol) with aerobic and anaerobic sediment and seawater (28 ‰) sampled from the intertidal Flax Bond Saltmarsh (NY). A slurry volume of 2.5 to 10 ml was employed in the tests and all slurry incubations were conducted in 20 ml vials in the dark under continuous shaking. Test and pre-adaptation concentrations of 1 to 1000 ppm (1 to 1000 µg per g dwt sediment) were used and incubation times were between 7 and 28 days, depending on the test. The biodegradation of the parent compound was measured with non-adapted microorganisms under aerobic and anaerobic conditions at 25 °C and a concentration of 100 µg/g sediment. Ultimate biodegradation was observed in the aerobic vials. The amount of evolved $^{14}CO_2$ was 11 % (28 days) calculated on the basis of the initial concentration. Primary degradation of anthracene reached 99 % of the initial amount. $^{14}CO_2$-evolution lagged 18 to 20 days, but anthracene disappearance did not show any lag. It must be noted, that the pool of anthracene in the extraction residues was not measured and thus it is not possible to estimate the quantity of total primary degradation. The authors observed a complete lack of degradation in anaerobic conditions but degradation started immediately after oxygen addition, indicating that facultative microbial degraders were present..

Among the environmental factors studied by Bauer et al. (1985), mineralisation was concluded to be mainly influenced by oxygen concentration and temperature. The test on temperature dependency showed a doubling at 20 ºC and tripling at 30 ºC of the mineralisation rate compared to the lowest test temperature of 10 ºC. In all trial variations, slurries pre-adapted to 100 µg anthracene/g sediment were also tested and resulted in faster rates of mineralisation and anthracene disappearance. A maximum of 47 % mineralisation was observed in a trial with 14 days pre-adaptation of the inoculum to 100 µg anthracene/g sediment. It must be noted, that in the study of Bauer et al. (1985) the very small size of the batches, the large relation of sediment:water volumes and shaking are assumed to have enhanced the biodegradation in comparison to environmental conditions. In addition, the quality of seawater and sediment samples was not described.

In line with the results of Bauer et al. (1985), PAHs in general are considered to be persistent under anaerobic conditions (e.g., Neff, 1979; Leduce et al., 1992) with the consequence that they persist in anaerobic sediment, which normally means in the bulk of sediment, except of the top few aerobic millimetres.

An experimental study of the fate of PAHs including anthracene in a controlled marine ecosystem enclosure (depth 15 m) has been described by Lee et al. (1979). Crude oil was enriched with several PAHs, including anthracene. A suspension containing ^{14}C-radiolabeled hydrocarbons was released into the marine water enclosures. After incubation for various time intervals (max 17 days) at 12 °C in the dark, released $[^{14}C]CO_2$ was measured. The results are based only on measuring the recovery rates in the water column.

In the study anthracene dissipated from the water column with half lives of 3-6 days due to partitioning into sediment and volatilisation. In the sediment no degradation was measured and therefore no half lives could be determined for this most relevant compartment. Since total recovery was not determined the loss of anthracene from the water phase cannot be explained completely.

The study is not reliable, because the results are only based on the recovery rate. However, recovery was incomplete, and residues were not analytically determined.

Another study has been conducted by Bestari et al., 1998. The fate of PAHs in water and sediment was observed following direct application of liquid creosote to aquatic microcosms. 14 Microcosms were treated with nominal creosote concentrations ranging from 0.06 to 109 mg/l and 2 microcosms served as controls. The results indicate that PAH concentrations (including anthracene) in sediment show a high residue level after a time period of 84 days. The study is reliable with restrictions since no half lives for the single compounds in the sediment were derived. Moreover the authors did not differentiate between sedimentation, biological degradation, biotransformation and photolysis. Therefore a conclusion on the persistence of anthracene in sediment is not possible.

Marine cyanobacteria *Oscillatoria salina* Biswas, *Plectonnema terebrans* Bornet et Flahault, and *Aphanocapsa* species degraded Bombay High crude oil in flasks containing seawater with a salinity of 25 ‰ and pH of 5.7-8.2. The cultures were incubated under 12h:12h light and dark cycle at 28^{o} C. Light was provided by two fluorescent lamps of 40 W placed at distance of approximately 40 cm. After 10 days 90.6 % of anthracene contained in the crude oil added was degraded by *Oscillatoria salina*, 62.7 % by *Plectonnema terebrans* and 41.9 % by *Aphanocapsa species* (Raghukumar et al., 2001). In addition, methanogenic bacteria retrieved from marine sediment by Rockne et al. (1998) and *Rhodococcus* species, sampled from polluted river sediment by Dean-Ross et al. (2001), have been observed to degrade anthracene. These studies are considered as evidence that anthracene can be biodegraded by certain organisms but the rate of biodegradation at environmentally relevant conditions cannot be determined on the basis of this information

Biodegradation in soil

Bacteria, fungi, yeasts and algae are known to degrade PAHs. Bacteria are generally assumed to be the most important group of soil micro-organisms contributing in the biodegradation of PAHs in soils (European Commission, 2007b).

Mackay et al. (1992) allocated anthracene to persistency class 6 for soil corresponding to half-lives of 125-420 days. These half-lives were applied in the risk assessments of anthracene and coal tar pitch, high temperature (European Commission, 2007a, 2007b).

Biodegradation rates of anthracene and other PAHs in soil depend on several factors like soil type, pH, moisture content, oxygen and nutrient contents and soil microbial population. In addition, vegetation has been observed to enhance microbial biodegradation in the rhizosphere. Some of these factors may also explain why the half-lives observed under laboratory conditions are much shorter than those obtained from long-term field-based experiments (European Commission, 2007b). The results of Wild et al. (1991) and Wild and Jones (1993) demonstrate the difference of tests conducted for several PAHs in field conditions compared to laboratory tests. Wild et al. (1991) observed a half-life of 7.9 years for anthracene in a field experiment with soils enriched with PAH-contaminated sludge, whereas Wild and Jones (1993) derived half-lives of 48-120 days in their microcosm study with three soil types. It has to be noted that the latter results are derived from a greenhouse study and should therefore not be used for the P-assessment.

Various studies on PAH-contaminated soils have shown that the number of PAH-degrading micro-organisms and the degrading capacity are much higher in PAH-contaminated soils than in pristine

soils indicating that adaptation has occurred. This finding is applicable also to anthracene (European Commission, 2007a, 2007b).

3.1.3 Summary and discussion of persistence

Based on the reviewed information it can be concluded that in general degradation of anthracene is limited by its low water solubility and its strong tendency to adsorb to particles and organic matter.

Once released to aqueous systems, anthracene is expected to partition to sediment due to its tendency to adsorb to particles and organic matter. To some extent anthracene might also volatilise and be degraded in air by photo-oxidative processes. Some studies indicate that anthracene might be degraded in water by highly adapted micro-organisms under aerobic conditions. However, most of the available studies on biodegradation resulted in negligible or slow mineralisation rates.

In sediment mineralisation half-lives of up to 210 days were determined by Lee & Ryan (1983) showing that anthracene fulfils both the P-criterion and the vP-criterion in sediment. In a field study addressing fate and behaviour of anthracene in soil a half-life of 7.9 years was determined (Wild et al. 1991) indicating that the substance is very persistent in soil.

3.2 Environmental distribution

3.2.1 Adsorption/desorption

An organic carbon partitioning coefficient logKoc of 4.47 (Koc 29,512) was calculated using the equation logKoc = logKow – 0.21 (Karickhoff et al., 1979) and the logKow of 4.68. The equation was developed based on sediment data, but data from soils also fit the equation (Karickhoff, 1981). An overview of other methods for determining the Koc for PAHs has been described by European Commission (2007b). It can be concluded that anthracene has a high potential to adsorb to organic matter and that it is not mobile in soil and sediment.

Adsorption of PAHs to black carbon has been reported in several studies to be considerably higher than adsorption to organic carbon available in the environment. However, the bioavailability studies carried out so far did not show decreased bioavailability in the presence of black carbon. In addition, the residence time of PAHs in soil and sediment seems to enhance sorption. This phenomenon is called aging and it has been observed to affect the bioavailability of PAHs in some conditions (European Commission, 2007b).

3.2.2 Volatilisation

According to its vapour pressure ($9.4 * 10^{-4}$ Pa at 25 ºC), anthracene is slightly volatile. The Henry constant of 3.56 Pa m^3 mol^{-1} (at 25 °C) calculated using water solubility of 0.047 mg l^{-1}) indicates that anthracene is moderately volatile from water. This result is in agreement with another reported value (4.3 Pa m^3 mol^{-1} at 25 °C; Mackay, 1992).

Due to the high partitioning to solids, very low concentrations of anthracene in aqueous solutions are expected and the share of anthracene volatilised remains therefore very small. Volatilisation is not considered a relevant distribution route of anthracene. Accordingly, EUSES 2.0 predicts that in the waste water treatment plant only 1.5% of anthracene is volatilised (European Commission, 2007a).

3.2.3 Long-range environmental transport

A short half-life in air (3.4 hours at 52 °C and 9,63 h at 25 °C) has been determined for anthracene. It is therefore not expected to be subject to long-range atmospheric transport.

3.3 Bioaccumulation

3.3.1 Aquatic bioaccumulation

3.3.1.1 Bioaccumulation estimation

Based on the logKow of 4.68, anthracene is expected to bioaccumulate.

3.3.1.2 Measured bioaccumulation data

Bioaccumulation of anthracene has been studied in various species. These studies are discussed in detail in the risk assessment of anthracene (European Commission, 2007a). Table 3 presents the results.

The data „Japan CITI 1992/NITE 2002“ (1992) are published in the official Japanese MITI-List. The study is valid with reliability 2. The study is in accordance with OECD 305 C (flow-through study over 8 weeks, 2 concentrations tested, test design improved for a volatile substance). Although test concentrations were lower than the water solubility of anthracene, a dispersant was used for enhancement of solubility. Considering the common extraction technique it remains unclear whether and to which extent the reported water concentrations may contain a fraction of undissolved dispersant-bound anthracene. In this case the reported BCFs could be underestimated. Overall, with BCFs of > 2000, the study clearly confirms that anthracene fulfills the B criterion.

In the studies of Spacie et al. (1983), De Maagd et al. (1996) and De Voogt et al. (1991) (all reliability 2) BCFs were mainly determined as quotient of uptake and elimination rate constants. This calculation may not be considered as an appropriate way to estimate steady state tissue concentrations if the test period is too short and biotranformation is important. However, if single-first-order kinetics is assumed, BCF-kinetics can be considered to be representative for BCF-steady state.

Furthermore, in the study of De Voogt et al. (1991) BCF-values from 4550 +/- 1600 and 6000 were determined with substance specific analyses of anthracene in water and fish and therefore these BCF-values refer to the "parent-compound". Because of the short uptake phase it is unclear whether steady state was reached. Hence the reported BCFs might still underestimate the real value.

3.3.2 Summary and discussion of bioaccumulation

In this dossier the bioaccumulation potential was evaluated using bioaccumulation studies with reliability 2. Considering these studies, BCF values in the range of 420 to 6000 were determined for the parent compound.

It is concluded that anthracene fulfils the B criterion.

Table 3: Bioconcentration factors of anthracene (For details and references see European Commission, 2007a)

Species	BCF	Test system	Type	Val.	References
Fish					
L. macrochirus	900	S	k_1/k_2 (total)	2	Spacie *et al.* (1983)
P. promelas	6760	S	k_1/k_2 (parent)	2	De Maagd *et al.* (1996)
P. reticulata	4550 (pref)	R	Equi (parent)	2	De Voogt *et al.* (1991)
P. reticulata	6000	S	Equi (parent)	2	De Voogt *et al.* (1991)
B. rerio	10400	S	k_1/k_2 (total)	3	Djomo *et al.* (1996)
L. macrochirus	675	S	k_1/k_2 (corrected)	3	Spacie *et al.* (1983)
O. mykiss	9000-9200	R	k_1/k_2 (parent)	3	Linder *et al.* (1985)
O. mykiss	779	R	Equi (parent)	3	Linder *et al.* (1985)
P. reticulata	7260	S	k_1/k_2 (parent)	3	De Voogt *et al.* (1991)
Salmo gairdneri	9,000-9,200				Linder *et al.* (1985)
Salmo gairdneri	143 µg/fish	OECD			Nimi *et al.* (1986)
Cyprinus carpio	1,660-2,820	OECD	2		Japan Chemical industry (1992)
Cyprinus carpio	903-2,710	OECD	2		Japan Chemical industry (1992)
Carassius auratus	162	S		4	Ogata *et al.* (1984)
L. melanotus	910	S	k_1/k_2 (unclear)	4	Freitag *et al.* (1984)
Mollusco					
U. imbecilis (larv.)	345 (highest 420)	R	Equi (parent)	2	Weinstein & Polk (2001)
Macona balthica (marine bivalve)	260	F		3	Clement *et al.* (1980)
Anodonta imbecilla (clam)	Little to no biotransformation	S		2	Giesy *et al.* (1982)
Crustacea					
Daphnia magna	970	B		3	Newsted and Giesy (1987)
Daphnia magna	511	S		3	Mc Carthy *et al,* (1985)
Daphnia pulex	1,192			4	Southworth (1978)
Daphnia pulex	1,085	S		4	Southworth (1978)
Daphnia pulex	988	S		4	Southworth (1978)
Daphnia pulex	917	S		4	Southworth (1979)
Daphnia magna	319-607	F		2	Leversee *et al.* (1982)
H. azteca	1800-10985	F	k_1/k_2	3	Landrum & Scavia (1983)
P. hoyi	16857-39727	F	k_1/k_2	3	Landrum (1982, 1988)
Algae					
Selanastrum capricornutum	5100-10500	S		3	Mailhot *et al.* 1987
Chlorellafusca var.vacuolata	7,770	S		3	Freitag *et al.* (1985)

S: static exposure system; F: flow-through system; B: batch test; R: static renewal system; k_1/k_2, kinetic: uptake rate/depuration rate; Equi: equilibrium; Val: validity (1: Reliable without restrictions, 2: Reliable with restrictions, 3: Not reliable, 4: Not assignable); OECD: OECD Guideline 305 C

4 ENVIRONMENTAL HAZARD ASSESSMENT

4.1 Aquatic compartment (including sediment)

Exposure to anthracene under UV-radiation enhances the ecotoxicity of anthracene, i.a., in fish, invertebrates and algae (European Commission, 2007a, 2007b). The mechanisms of photo-enhanced toxicity are not fully understood. For example, Huang et al. (1997) observed that photomodified anthracene exposure leads to the inhibition of photosystem II in *Lemna gibba*. The mechanism in animals can be expected to be very different. According to some studies, photodegradation products of anthracene forming under UV-light do not seem to cause this higher toxicity (e.g., Bowling et al., 1983; Allred and Giesy, 1985; Kagan et al., 1985) but also contradictory results have been presented (Huang et al., 1995). Enhanced effects have been attained already with very short exposures to natural sunlight or UV-light (0.5 to 6 hours) and with light intensities corresponding to conditions in several meters depth of natural waters. Hence, photoenhanced toxicity is considered a relevant phenomenon in the environment (unlike photodegradation, which is expected to be relevant only in the first few centimetres depth of typical natural waters).

Studies available on the toxicity to fish, invertebrates and algae are described in detail in the risk assessment of anthracene (European Commission, 2007a). The most reliable acute and chronic toxicity data for fish, invertebrates and algae are listed in Tables 4 to 8.

4.1.1 Toxicity test results

4.1.1.1 Fish

Short-term toxicity to fish

Table 4: Acute toxicity of anthracene to fish (European Commission, 2007a)

Species	Test duration	Measure of effect	Concentration (mg/l)	Remarks	Reference
Lepomis macrochirus	96 h	LC50	0.0119-0.0265	UV radiation at similar level as in 0.6 m depth of an eutrophic lake	Oris et al., 1984
Lepomis macrochirus	96 h	LC50	0.003-0.026	Exposure under simulated sunlight	Oris and Giesy, 1985
Lepomis macrochirus	24 h light:0 h dark 6 h light:18 h dark	LC50 LC50	0.0045 0.046	Exposure under simulated sunlight; extrapolated values	Oris, and Giesy, 1986
Lepomis macrochirus	48 h	LC_{50}	0.0127	Natural sunlight conditions in artificial test channel; no toxicity to photodegradation products	Bowling et al., 1983
Pimephales promelas	24 h	LC 50	0.360	Simulated sunlight	Kagan et al. 1985
Oryzias latipes	24 h	LC 50	0.210		Ruetgerswerke, 1991

Long-term toxicity to fish

Table 5: Chronic toxicity of anthracene to fish (European Commission, 2007a).

Species	Exposure	Measure of effect	Effect	Conc. (mg/l)	Remarks	References
Lepomis macrochirus	200 h	NOEC	Survival	0.0012 - 0.0135	UV exposure	Oris and Giesy, 1986
Pimephales promelas	63 d	NOEC	Deformities	<0.006	Effects occurred in the presence and absence of UV exposure	Hall et al., 1990; Hall and Oris, 1991
Pimephales promelas	63 d	LOEC	Survival and hatching	0.012	Effects occurred in the presence and absence of UV exposure	Hall et al., 1990; Hall and Oris, 1991

4.1.1.2 Aquatic invertebrates

Short-term toxicity to aquatic invertebrates

Table 6: Acute toxicity of anthracene to invertebrates (European Commission, 2007a)

Species	Exposure	Measure of effect	Concentration (mg/l)	Remarks	References
Daphnia pulex	24 h	LC_{50}	0.001	Exposure under sunlight	Allred and Giesy, 1985
Daphnia magna	48 h	LC_{50}	0.036	Exposure in the dark	Abernethy et al., 1986
Daphnia magna	14 min	EC_{50}	0.0012	Exposure under UV light	Oris, et al., 1984
Daphnia magna	24-25 h	EC_{50}	0.0012	Effects both under sunlight and dark	Oris, et al., 1984
Daphnia magna	24 h 48 h	EC_{50}	0.211 0.0095		Munoz and Tarazona, 1993
Daphnia magna	48 h	EC_{50}	0.754		Smith et al., 1988
Daphnia magna	23 ± 1 h	EC_{50}	22µM		Huovinen et al., 2001
Daphnia magna	24 h	LT_{50}	0.015	298.5 min in the given concentration	Newsted and Giesy, 1987
Artemia salina	1 h	EC_{50}	0.2	Exposure under UV light	Diamond et al., 2000
Artemia salina	48 h	LC_{50}	>0.05		Abernethy et al., 1986
Artemia salina	10 h	EC_{10}	0.023		Peachy and Crosby, 1996
*Mysidopsis bahia**	48 h	LC_{50}	0.0036	Exposure under UV light	Pelletier et al., 1997
*Mysidopsis bahia**	48 h	LC_{50}	0.535	Exposure under fluorescent light	Pelletier et al., 1997
Culicid mosquito (larvae)	24 h	LC_{50}	0.0268		Oris et al., 1984
Aedes aegypti	24 h 1 h	LC_{50} LC_{50}	<0.001 0.15	Effects both under sunlight and dark	Kagan et al., 1985
Utterbackia imbecillis	24 h	LC_{50}	0.00193	Exposure under UV light	Weinstein, et al., 2001
Mulinia lateralis * (embryo-larvae)	48 h	LC_{50}	0.00647	Exposure under UV light	Pelletier et al., 1997
*Mulinia lateralis** (embryo-larvae)	48 h	LC_{50}	4.260	Exposure under fluorescent light	Pelletier et al., 1997
Mulinia lateralis * (juvenile)	96 h	LC_{50}	0.0689	Exposure under UV light	Pelletier et al., 1997
*Mulinia lateralis** (juvenile)	96 h	LC_{50}	13.3	Exposure under fluorescent light	Pelletier et al., 1997
Nereis areaceodentata	96 h	LC_{50}	0.051		DEFRA

* Marine species

Long-term toxicity to aquatic invertebrates

Daphnia magna were exposed to anthracene in the presence and absence of ecologically relevant intensities of UV radiation for 21 days. Exposure to 8.2 µg l^{-1} anthracene in the absence of UV radiation reduced the number of neonates produced by 13.8 %. Exposure to UV radiation in the absence of anthracene had no significant effect on the fecundity. Simultaneous exposure to UV radiation and anthracene resulted in further reduced survival and fecundity. Exposure to 7.2 µg l^{-1} anthracene and 117µW cm^{-2} UV-radiation resulted in 70% mortality and 69% decrease in production of neonates by adults that survived. The NOEC under UV exposure (UV-A 117 µW/cm²) was 6.8 µg/L. (Holst and Giesy, 1989).

Photoenhanced effects of anthracene on reproduction of *Daphnia magna* in terms of total clutch size and survival over a 21 d period were reported by Foran, et al. (1991). The NOEC under exposure to UV light was 1.9-2.2 µg l^{-1} and without UV exposure the NOEC was 2.2 µg l^{-1}.

Table 7: Chronic toxicity of anthracene to invertebrates

Species	Exposure	Measure of effect	Concentration (mg/l)	Remarks	References
Daphnia magna	21 d	NOEC	0.0068	Exposure under UV light	Holst and Giesy, 1989
Daphnia magna	21 d	NOEC NOEC	0.019 0.0022	Exposure under UV/ without UV light	Foran, et al. 1991

4.1.1.3 Algae and aquatic plants

Results between EC_{50}(22h) of 0.004 mg l^{-1} for *Selenastrum capricornutum* (Gala and Giesy, 1992) and EC_{50}(24h) of 2.53 mg l^{-1} for *Chlorella protothecoides* (Yan et al., 1999) have been observed with and without simultaneous exposure to UV –radiation. A NOEC of 0.0015 mg l^{-1} was derived for *Selenastrum capricornutum* by the same authors (Gala and Giesy, 1992).

Table 8: Toxicity of anthracene to algae

Species	Exposure	Measure of effect	Concentration (mg/l)	Remarks	References
Selenastrum capricornutum	22 h	EC_{50} NOEC (EC_{10})	0.004 0.0015	With UV light (UV-A 765 µW/cm²)	Gala and Giesy, 1992
Chlorella protothecoides	24 h	EC_{50}	2.53	With and without UV light	Yan et al., 1999

5 PBT, VPVB AND EQUIVALENT LEVEL OF CONCERN ASSESSMENT

5.1 Comparison with criteria from Annex XIII

Persistence: Biodegradation screening tests with sludge indicate that anthracene is not readily degradable. Biodegradation tests employing water and sediment-water mixtures are available showing slow to very slow mineralization. Mineralization half-lives up to 210 days have been reported for aerobic sediment, whereas under anaerobic conditions anthracene is completely recalcitrant. In addition, a half-life of 7.9 years has been observed in soil in a field study. Based on these data, anthracene is considered to be very persistent in sediment and soil.

Bioaccumulation: BCFs in the range of 420 to 6000 have been measured for the parent compound. It is concluded that anthracene fulfils the B criterion.

Toxicity: NOECs in the range of 0.0012 to 0.012 mg l^{-1} from three long-term tests with fish are available. For *Daphnia magna*, 21d-NOECs of ca. 0.002 mg l^{-1} have been determined. For algae, acute toxicities have been reported with EC_{50} –values from 0.004 to 2.53 mg l^{-1}. The most sensitive species is *Daphnia pulex* with LC_{50}(48h) of 0.001 mg l^{-1} under sunlight. It is concluded that anthracene fulfils the T criterion.

5.2 Conclusion of PBT and vPvB or equivalent level of concern assessment

Anthracene is considered to meet the P and vP, the B and the T criteria. Hence, anthracene is concluded to be a PBT substance.

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