Environmental risks assessments of flame-retardant found in EPS bridge embankments

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Summary
EPS blocks are used as fill material in "super lightweight" bridge embankments. Since 1974 expanded and extruded polystyrene foams (EPS and XPS) has been produced with a content of hexa-bromo-cyclo-dodecane (HBCDD), a brominated flame-retardant (BFR). In 2005 the Norwegian Public Roads Administration (NPRA) banned the use of BRFs in new EPS-blocks. This was due to a specific concern from the Norwegian Environmental Authorities. The same concern implied that HBCDD in 2008 was included in EUs candidate list for Authorization based on its persistent, bio-accumulative and toxic (PBT) properties.

With respect to the BRFs in EPS and soil samples taken from bridge sites it must be concluded, that:

- *The content of HBCDD in the EPS blocks was high and at a level comparable to the expected content based on production information /1/.*
- *The content of HBCDD in soil below the EPS blocks was below the limit of detection (0,2 mg/kg DM), which also is the level of the guidance value from 2006 and more than 10 times less than EU PNEC value form 2008.*
- *The risk of exposure for humans and the environment to HBCDD from the EPS blocks is low. At the end of life EPS is handled as a hazardous waste according to national regulations.*
- *PBDEs have not been detected in the EPS-blocks, only in the upper soil samples.*
- *The content of penta-BDE in soil samples was below 0.1 mg/kg DM, which is more than 3 times lower than the guidance value. This concentration level is less than predicted environmental regional agricultural soil concentration /16/. Specific sources are not located.*

INTRODUCTION

In 1989 EPS-blocks were applied as super lightweight embankments at Løkkeberg and Hjelmungen bridges in the county of Østfold, Norway. This section of the road was in 2006 replaced leaving a large number high quality expanded polystyrene (EPS) blocks available for reuse /10/. Disposal would mean handling of the EPS blocks as hazardous waste due to its high content (>0.25%) of the brominated flame retardant (BRF) hexa-bromo-cyclo-dodecane (HBCDD). Due to the awareness of environmental hazards from HBCDD a

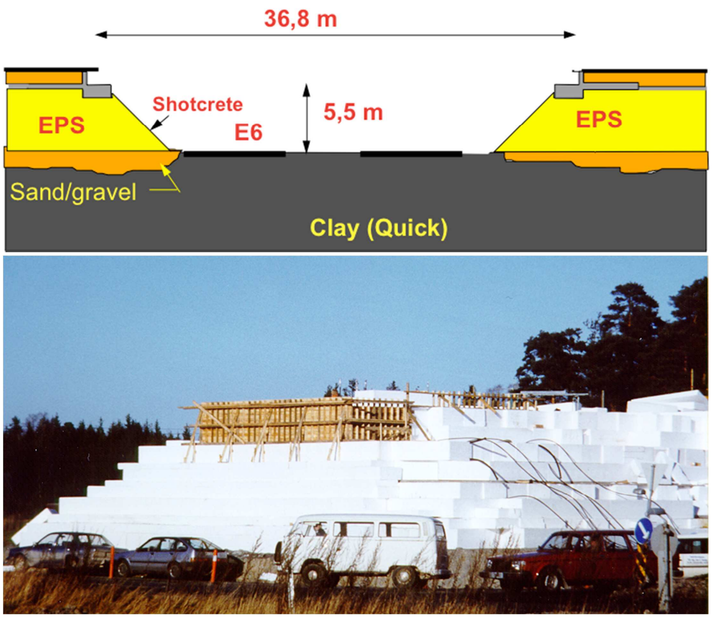

Figure 1. Abutment on EPS at Løkkeberget bridge

site-specific environmental risk assessment was performed. This document presents the recently updated risk assessment from 2006 including information regarding environmental hazards from HBCDD in EPS-blocks and penta-bromo-di-phenyl-ether (penta-BDE) found in soils under the constructions.

Fire requirements and legislation have driven forward different organic and inorganic chemical solutions for fire protection. Approximately 200 substances are used in commercial flame retardant products /11/. BFRs are chemical compounds containing bromine bound to a carbon skeleton and are an additive to the EPS. The BFRs have routinely been added to consumer products for several decades in a successful effort to reduce fire related injury and property damage /2/. Flame-retardants are used in the manufacture of electronic equipment, upholstered furniture, construction materials, and textiles in order to meet high fire safety requirements /3/. Furthermore especially HBCDD is used in *expanded and extruded polystyrene foams* (EPS and XPS) utilized in building and construction, styrene resins, latex binders, *high impact polystyrene* (HIPS), unsaturated polyesters and in textile coatings /4/.

BFRs are generally divided into four groups, based on the chemical structure of the carbon skeleton. The four groups of BFRs and the generally used abbreviations are:

Polybrominated biphenyls	PBB
Decabromodiphenyl ether (Deca-BDE) Octabromodiphenyl ether (Octa-BDE) Pentabromodiphenyl ether (Penta-BDE)	Polybrominated Diphenyl Ethers PBDEs
Hexabromocyclododecane	HCBDD
Tetrabromobisphenol-A	TBBPA

Due to cases of poisoning in the USA PBBs were removed from the market in the early 1970s /2/. Furthermore a voluntary ban on penta-BDE was formalized in Europe as of July 2003, and a restriction on the use of penta-BDE and Octa-BDE in electrical and electronic equipment by July 2006 in the European Union. Penta- and octa-BDE are now classified under the European Union POP (persistent organic pollutant) regulations, and are banned.

Since 1974 EPS-blocks have been produced with a content of HBCDD. On 28 October 2008 HBCDD was included on the EU candidate list for Authorization based on claimed PBT and potential POP properties /12/. On 28 of November the same year the industry comments that HBCDD did not meet the “persistent” (P) criteria (half-life >180 days sediments) in the European Union POP (persistent organic pollutant) regulations /13/. The use of fully valid biodegradation simulations using environmental relevant HBCDD concentrations (around 25 µg/l) was urged to get more realistic half-life times. There is an ongoing evaluation on the handling and use of HBCDD in the European Union. Norwegian environmental authorities have suggested that HBCDD should classify as a POP. Reports have been published from the European Brominated Flame Retardant Industry Pane (EBFRIP) /14/ and the European Chemicals agency /15/ concluding that HBCDD does fulfill the European Union criteria for persistent, bio-accumulative and toxic (PBT) chemical. HBCDD are for the time being suggested regulated from consumer goods. Norwegian regulations define that a waste product containing more than 0.25% HBCDD has to be handled as hazardous waste.

The Norwegian Environmental Authorities concern for environmental effects from HBCDD made NPRA recalculate the fire risk connected to EPS in road embankments. They concluded that the environmental concerns and risks form BRFs was higher and that the risk of fire was low for EPS-blocks. NPRA no longer use new EPS-blocs containing BRFs. Tetrabromobisphenol-A (TBBPA) is further described in risk assessment from KEMI /5/. TBBPA has no further relevance in this article.

MATERIALS AND METHODS

Flame retardant EPS-blocks from 1989 were applied in super lightweight bridge embankments that were removed in 2006. The decision to reuse the 17 year old EPS-blocks in a new lightweight embankment was based on their excellent technical condition /10/ and an environmental risk assessment. The environmental risk assessment and interpretation was based on the following work:

1. Sampling of EPS-blocks at bridge embankments at Løkkeberget and Hjelmungen /10/. At each location minimum 3 samples from inside the EPS block were mixed to one sample. The samples were analyzed for brome (Br), BRFs, heavy metals, BTEX, phthalates and PCBs (appendix C). Chemical analysis was done at an accredited laboratory, Analycen AS, using accredited methods.
2. Sampling of soil under the two EPS embankments (Løkkeberg, figure 1). Soil level 3-10 cm and 10-20cm under EPS-blocks and 140-145 cm was sampled approximate 11 meter on the downstream side of the construction site. Soil samples were analyzed for BRFs.
3. Risk assessment dataset was based on available literature from the Internet. Guidance values for soil and surface water are based on eco-toxicological values. Calculated human health based guidance values are calculated according to Norwegian guidelines /8/.

Figure 2. Soil and EPS-blocks at Løkkeberget. Left and bottom right pictures: EPS-blocks (1989) and soil profile 0-20cm. Top right picture: Reference soil profile 0-140 cm (Photo: Tor Helge Johansen, NPRA, year 2006)

RESULTS AND DISCUSSION

Chemical analysis

The chemical analysis contained a wide range of environmental pollutants (appendix C). BRFs of concern are listed in table 1. No other BRFs were detected. The only BRFs found in EPS were HBCDD. The content was documented to be 1260 mg/kg and 6300 mg/kg. The "expected " content was approximately 0.7% or 7000 mg/kg, and the density is 30 kg/m^3 /1/. HBCDD was not detected in the soil samples (<0.2 mg/kg). In the soils the only BRFs detected were penta-BDE and tetra-BDE. Concentrations was respectively 0.095, 0.044, 0.012 and <0.05 mg/kg DM, and tetra-BDE of 0,029, 0,011, <0.05 and <0.05 mg/kg DM.

Table 1. Chemical concentrations of selected BRFs from EPS-blocks and soils. Analyzed metals and chemicals are showed in appendix C. Samples are from the bridge locations at Løkkeberget and Hjelmungen, Norway /10/. Levels are given relative to topsoil. Unit is µg/kg dry mass.

Location	Løkkeberge, Halden	Hjelmungen	Hjelmungen	Hjelmungen	Løkkeberge, Halden	Løkkeberge, Halden
Sample name/Description	EPS-plates	7/6-06 EPS-plates	Sandy layer under EPS. Level 2-5cm	Under EPS. 5 cm thick layer representing shift form sand to clay	Sandy layer under EPS. Level 2-10cm	11 m at the side. Silty-sandy approx. 5cm above clay. level 140-145cm
Samping date	11.05.2006	07.06.2006	25.07.2006	25.07.2006	25.07.2006	25.07.2006
Dry Weight (%)	86.5	100	93.8	81.3	94	92.1
Hexabromocyclododecan, HBCDD (µg/kg DW)	**1260000**	**6300000**	<200	<200	<200	<200
'Heksabromodiphenylether, PBDE-138 (µg/kg DW)	<5	<5	<5	<5	<5	<5
'Heksabromodiphenylether, PBDE-153 (µg/kg DW)	<20	<20	<20	<20	<20	<20
'Heksabromodiphenylether, PBDE-154 (µg/kg DW)	<5	<5	<5	<5	<5	<5
Heptabromodiphenylether, PBDE-183 (µg/kg DW)	<20	<20	<20	<20	<20	<20
Heptabromodiphenylether, PBDE-190 (µg/kg DW)	<100	<100	<100	<100	<100	<100
Pentabrombifenyl, PBB-101 (µg/kg DW)	<5	<5	<5	<5	<5	<5
Pentabromodiphenylether (sum) (µg/kg DW)	<5	<5	**94.9**	**44.1**	**11.6**	<5
Pentabromodiphenylether, PBDE-100 (µg/kg DW)	<5	<5	**8.7**	<5	<5	<5
Pentabromodiphenylether, PBDE-99 (µg/kg DW)	<5	<5	**86.3**	**39.9**	**10.5**	<5
Tetrabrombifenyl, PBB-52 (µg/kg DW)	<5	<5	<5	<5	<5	<5
Tetrabrombisfenol A, TBBFA (µg/kg DW)	<5	<5	<5	<5	<5	<5
Tetrabromodiphenylether, PBDE-47 (µg/kg DW)	<5	<5	**29.3**	**10.8**	<5	<5
Tribromodiphenylether, PBDE-28 (µg/kg DW)			<5	<5	<5	<5

Risk assessment HBCDD

HBCDD is a cyclic aliphatic compound used as an additive flame retardant in thermoplastic polymers as polystyrene resins etc. The technical product consists of three diastereomers, α, β and γ. The predominant isomer in the technical product is the γ isomer with app. 85 % of the product. The isomers behave different in the environment due to differences in structural composition.

The physical-chemical and environmental relevant properties of HBCDD are shown in table A1 in appendix A.

HBCDD is a highly lipophilic compound with a high log KO_W and a low solubility in water. Because of the high degree of halogenation it has a low vapor pressure. Studies have shown that HBCDD bio accumulates in the food chain.

The Swedish national institute KEMI has made a review report on HBCDD in order to evaluate the consequences of a national ban on the substance /5/. The report is based on the draft European Risk Assessment on HBCDD from 2005, which has not been found in the literature search in this study.

In the report by KEMI predicted no effect concentrations (PNECs) have been reported for surface waters (0,0031 mg/l), marine waters (0,000031 mg/l), sediment (0,86 mg/kg DM), soil (0,177 mg/kg DM) and oral intake (0,74 mg/kg BM). In rats a value of 10 mg/kg BM/day has been reported as a *Lo-Observed-Adverse-Effect-Level* (LOAEL) value.

In a review report by the German EPA a MTDI value of 0.2 mg/kg BM/day has been reported /6/. This value is based on a *No-Observed-Adverse-Effect-Level* (NOAEL) of 450 mg/kg BM. In a later paper by the Swedish EPA it is stated that in mammals, the liver and thyroid system is affected after repeated exposure to HBCD, but no conclusive NOAEL can be set /7/.
Based on the above information regarding the value of the NOAEL it must be concluded, that the MTDI value must be at least a factor 200 lower than calculated by the German EPA. An estimate of the MTDI value will hence be 0.001 mg/kg BM/day.

Based on the above MTDI value and the physical chemical properties of HBCDD a calculation of the total human exposure has been performed according to the procedures described by the *Norwegian Pollution Control Authority* (SFT) /8/. The dataset used results of the calculations are shown in table A3 and table A4 in appendix A.

The calculations show that a human health based soil guidance value for HBCDD is 0.998 mg/kg DM. It must be stated that the derived human health based soil guidance value is a technically derived value, and not a politically stipulated value.

The calculated value is higher than the eco-toxicological $PNEC_{soil}$ of 0.177 mg/kg DM.
The calculated PNEC values from 2006 were in 2008 replaced by an EU risk assessment report (RAR) also from The Swedish Chemicals Agency (KEMI) /12/. $PNEC_{soil}$ (terrestrial compartment) use an assessment factor of 10 and is 59/10=5.9 mg/kg dry soil. $PNEC_{sediments}$ use an assessment factor of 50 and use the same data for fresh and marine sediments 8.6/50=0.17 mg/kg dry sediment. PNECwater use an assessment factor 10 and is 3.1/10=0.31 µg/l. Marine waters have a higher assessment factor and lower PNEC.

Risk assessment Penta-BDE

Penta-BDE is diphenyl-ether containing five atoms of bromine. The commercial penta-BDE product is a mixture of mainly tetra- and pentabromodiphenyl ethers, with small amounts of tri-, hexa- and heptabromodiphenyl ethers /9/.

In 2005 penta-BDE was proposed as a *Persistent Organic Pollutant* (POP) for the UNEP Stockholm convention on POPs by the Norwegian government /10/. The physical-chemical and environmental relevant properties of Penta-BDE are shown in table B1 in appendix B.
Penta-BDE is highly lipophilic compound with a high log KO_W and a low solubility in water. Because of the high degree of halogenation it has a low vapour pressure. Studies have shown that penta-BDE bio accumulates in the food chain.

The RIKZ institute in the Netherlands calculated an iMTR value ("indicative Maximum Tolerable Risk level") at a 95% protection level for surface water and sediment using either the US-EPA method or the equilibrium partition method /11/. Due to sparse amounts of toxicological data high safety factors were used. The calculations resulted in very low concentrations in surface water (0.014 µg/l) and sediment (21 µg/kg). The European Chemicals Bureau calculated a *predicted no effect concentration for surface water* ($PNEC_{water}$) using an assessment factor of 10 resulting in a value of 0,53 µg/l /12/. Furthermore a $PNEC_{soil}$ (terrestral compartment) was derived using an assessment factor of 50 resulting in a value of 0.38 mg/kg DM. The acute mammalian toxicity of commercial penta-BDE is low (LD50 > 1 g/kg body weight) in laboratory animals /11/.

A risk profile on commercial penta-BDE has been elaborated by UNEP giving a review on the toxicological and eco-toxicological data on this substance /10/. The review states that studies on penta-BDE have demonstrated reproductive toxicity, neuro-developmental toxicity and effects on the thyroid hormones. Furthermore it is presumed that the chemical group of PBDEs is endocrine disrupters, but research results in this area are scant. The NOEL of penta-BDE reported in the review is 0.06 – 3 mg/kg/day.

It is furthermore stated that penta-BDE accumulates in the human body, and it is believed that long-time exposure to lower doses can cause health effects. However, since the half-life of penta-BDE in humans is unknown it is not possible to conclude on long-time exposure effects. The US-EPA database IRIS (Integrated Risk Information System) /13/ reports a *Reference Dose for oral Exposure* (RfD) of 0.002 mg/kg/day using an uncertainty factor of 1000 with a NOAEL of 1.77 mg/kg/day. The RfD value is based on a study from 1980, The lowest NOEL level in the UNEP review paper is a factor 20 lower than reported in the IRIS database. However since the number of tested endpoints is raised the uncertainty factor could be lowered to 100, a conservative estimate of a *Maximum Tolerable Daily Intake* (MTDI) is 0.001 mg/kg BM/day.

Guidance values and findings

In order to generate soil guidance values regarding the content of the two identified brominated flame-retardants a risk assessment has been performed (previous chapters). The risk assessment was based on a literature study including documents and reports found on the Internet. The general findings from 2006 are still valid in 2011.

Based on the data found in literature and calculations performed using the procedures described by the Norwegian Pollution Control Authority soil guidance values has been calculated regarding the human health risk. The calculated soil guidance values are in both cases higher than eco-toxicological risk based guidance values.

Based on the performed risk assessment and calculations it must be concluded, that technical guidance values for the two compounds – HBCD and penta-BDE – in soil as well as in surface water should be based on eco-toxicological values. The proposed values are shown in table 2 below.

Table 2. Guidance values derived for organisms in soil (soil mg/kg DW) and surface water (µg/l).

Technical guidance derived 2006/2008

Compound	Soil	Surface water	Remarks
HBCD	0.18/5.9	3.1/ 0.31	Based on eco-toxicological values
penta-BDE	0.38	0.53	Based on eco-toxicological values

The only BRFs found in EPS were HBCDD. The content was documented to be 1260 mg/kg and 6300 mg/kg. HBCDD is a highly lipophilic compound with a high log KO_W and a low solubility in water. Because of the high degree of halogenation it has a low vapor pressure. Under the given conditions no leaching into the soil was detected. Detection limit (0.02 kg/kg) is similar or less than soil guidance values from 2006 and 2008.

Despite the fact that no other BFRs than HBCDD were detected in the EPS blocks. Penta-BDE is, as HBSDD, a highly lipophilic compound with a high log KO_W and a low solubility in water. Because of the high degree of halogenation it has a low vapour pressure. The soil samples showed a content of penta-BDE of 0.095, 0.044, 0.012 and <0.05 mg/kg DM, and tetra-BDE of 0.029, 0.011, <0.05 and <0.05 mg/kg DM. The documented concentrations are less than the soil guidance values.

The only soil sample without a detectable content of BFRs was taken just above a layer of marine clay on the downstream side of the EPS-blocks (level 140-145 cm). This sample was taken approximate 10 meters away from the construction area. The findings support the fact that PBDEs has low mobility with water in the soil. The PBDEs are likely to originate from a diffuse source and probably from the construction period and use of the road. The concentrations are less than regional predicted environmental concentration for agricultural soils (PEC_{soil}=0.13 mg/kg wet weight) /16/.

The flame retarders PBB and TBBFA were not detected in the EPS or in the soil (<0,005 mg/kg).

CONCLUSION

The literature study, based on available documents and data on the Internet, have shown that sufficient data could be found to perform a risk assessment. It was also possible to calculate guidance values for soil and surface water for the two identified BFRs in soils and EPS-blocks from bridge embankments at Hjelmungen and Løkkeberget, Norway /10/.

Risk assessment have shown that both BRF compounds, HBCDD and penta-BDE, are expected to be able to bio-accumulate in the food chain. Furthermore the acute mammalian toxicity of both compounds is low, whereas the toxicity to algae and daphnia (“water fleas”) is high.

The compounds have low solubility, low vapor pressure and high affinity to organic carbon, resulting in very low mobility in the environment. This is supported by the soil samples.

Due to the very low mobility in the environment and the ability to bio accumulate in the food chain the critical routes of human exposure are expected to be intake via food or via soil (dust) on a contaminated site. These expectations are confirmed by the results of the calculations in appendix A and B.

The values are technically derived values and not politically stipulated values.
With respect to the EPS and soil samples taken at the bridge embankments and analyzed by AnalyCen AS it must be concluded, that:

- The content of HBCDD in the EPS blocks was high and at a level comparable to the expected content based on production information /1/.
- The content of HBCDD in soil below the EPS blocks was below the limit of detection (0.2 mg/kg DM), which also is the level of the guidance value from 2006 and more than 10 times less than EU PNEC value form 2008.
- The risk of exposure for humans and the environment to HBCDD is low. At the end of life EPS is handled as a hazardous waste according to national regulations.
- PBDEs have not been detected in the EPS-blocks, only in the upper soil samples.
- The content of penta-BDE in soil samples was below 0.1 mg/kg DM, which is more than 3 times lower than the guidance value. This concentration level is less than predicted environmental regional agricultural soil concentration /16/. Specific sources are not located.

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Appendix. A HBCDD – Properties

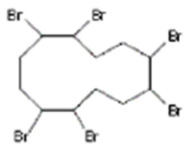
Name	Hexabromocyclododecane (HBCD)
CAS no.	25637-99-4 or 3194-55-6
Chemical composition	$C_{12}H_{18}Br_6$
Chemical structure	
Molecular weight	641,7 g/mole
Melting point	190°C
Boiling point	Decomposes >200 °C
Solubility	0.066 mg/l @ 20 °C
Log K_{ow}	5.625 @ 25°C
Vapour pressure	6.4 x 10^{-6} Pa (10°C)
Henry's law constant	11.89 Pa x m^3/mole @ 20-25°C

Table A1 Physical-chemical properties for HBCD /5/

Organism	Endpoint	Result	Remark	Ref.
Algae (marine)	EC50	0,0093 – 0,37 mg/l	Growth (72h)	/13/
Dahpnia	EC50	> 0,0068 mg/l	(48h)	/6/
Daphnia	NOEL	Ca. 0,0034 mg/l	(21d)	/6/
Daphnia	LOEL	0,0056 mg/l	(21d)	/6/
Fish	LC50	>0,0068 mg/l	(96h)	/6/

Table A2 Eco-toxicological properties for HBCD

Parameter	Data	Ref.
Ecotoxicology		
Terrestrial toxicity		
Plants, earthworms and soil-dwelling microorganisms	PNEC : 0,177 mg/kg DM Based on survival and reproduction test with earthworms - NOEC	/5/
Aquatic toxicity		
Fish, invertebrates and algae	PNEC : 0,31 µg/l PNEC marine: 0,031 µg/l	/5/
Accumulation		
Log P_{ow}	5,6	Table A1
BCF Fish	39.810	
BCF Stem	3,71	Calc. according to /8/
BCF Root	620	
Adsorption/Partition		
K_d	964	Calc. according to /8/
K_{oc}	96.380	
H	4.80 x 10^{-3}	
Human toxicology		
Oral intake		
MTDI (TRV)	0,001 mg/kg BW/day	/5/ and /6/ Recalculated
Dermal contact		
f_{du}	0,1	Worst case estimate

Table A3 Data used for calculating human exposure of HBCD

Parameter	Results
Oral intake of soil and dust - C_{is}	100 mg/kg
Dermal contact with soil and dust - C_{du}	476 mg/kg
Inhalation of dust - C_{id}	62.500 mg/kg
Inhalation of vapour – C_{iv}	792 mg/kg
Intake of drinkingwater - C_{iw}	144 mg/kg
Intake of vegetables - C_{ig}	1,03 mg/kg
Intake of fish etc. - C_{if}	89,1 mg/kg
Total Human Exposure - C_{he}	*0,998 mg/kg*

Table A4 Results of calculating human exposure of HBCD according to /8/

Appendix B. Penta-BDE – Properties (1:2)

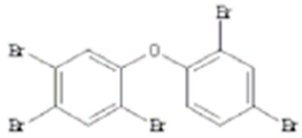
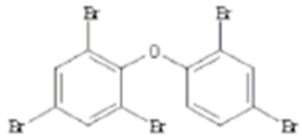
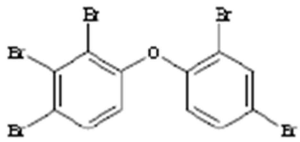
Name	Pentabromo-diphenyl ether (penta-BDE)
CAS no.	32534-81-9 60348-60-9 (2,2',4,4',5-PeBDE) 182346-21-0 (2,2',3,4,4'-PeBDE) 189084-64-8 (2,2',4,4',6-PeBDE)
Chemical composition	$C_{12}H_5Br_5O$
Chemical structure	 2,2',4,4',5-PeBDE  2,2',4,4',6-PeBDE  2,2',3,4,4'-PeBDE
Molecular weight	564,8 g/mole
Melting point	-7 to -3 °C (commercial product)
Boiling point	Decomposes >200 °C
Solubility	0.0133 mg/l @ 25 °C
Log P_{ow}	6.57 measured 7.66 (QSAR estimation)
Vapour pressure	4.69 x 10^{-5} Pa @ 21 °C (commercial product)
Henry's law constant	0,36 Pa m^3/ mol

Table B1 Physical-chemical properties for Penta-BDE /12,14/

Organism	Endpoint	Result	Remark	Ref.
Algae	NOEC	>0,026 mg/l	Growth (96h)	/11/
Daphnia	EC50	0,014 mg/l	Immobility (48h)	/11/
Daphnia	EC50	0,017 mg/l	Immobility (96h)	/11/
Daphnia	NOEC	0,0053 mg/l	Mortality Reproduction	/11/
Fish	NOEC	>0,021 mg/l	Mortality (96h)	/11/
Fish	LC50	>0,500 mg/l	(48h)	/11/

Table B2 Ecotoxicological properties for Penta-BDE

Appendix B. Penta BDE – Properties (2:2)

Parameter	Data	Ref.
Ecotoxicology		
Terrestrial toxicity		/12/
Plants, earthworms and soil-dwelling microorganisms	NOEC : 18,8 mg/kg DM (standard soil) PNEC : 0,38 mg/kg DM Assessment Factor : 50	
Aquatic toxicity		/12/
Fish, invertebrates and algae	Lowest NOEC : 0,0053 mg/l PNEC : 0,53 µg/l Assessment Factor : 10	
Accumulation		
Log P_{OW}	7	Table B1
BCF Fish	10^6	
BCF Stem	0,444	Calc. according to /8/
BCF Root	7410	
Adsorption/Partition		
K_d	27.540	Calc. according to /8/
K_{OC}	2.754.000	
H	1.45×10^{-4}	
Human toxicology		
Oral intake		
MTDI (TRV)	0,001 mg/kg BW/day	/10/ and /15/ Recalculated
Dermal contact		
f_{du}	0,1	Worst case estimate

Table B3 Data used for calculating human exposure for penta-BDE

Parameter	Results
Oral intake of soil and dust - C_{is}	100 mg/kg
Dermal contact with soil and dust - C_{dsu}	476 mg/kg
Inhalation of dust - C_{id}	62.500 mg/kg
Inhalation of vapour – C_{iv}	749.200 mg/kg
Intake of drinkingwater - C_{iw}	4.110 mg/kg
Intake of vegetables - C_{ig}	2,48 mg/kg
Intake of fish etc. - C_{if}	101 mg/kg
Total Human Exposure - C_{he}	*2,35 mg/kg*

Table B4 Results of calculating human exposure for penta-BDE according to /8/

Appendix C – Chemical analysis of EPS-blocks and soils. Units are mg or µg/kg dry mass. (1:3)

Labnummer from Analycen AS	NOV010376-06	NOV013570-06	NOV018767-06	NOV018768-06	NOV018769-06	NOV018770-06
Location	Løkkeberge, Halden	Hjelmungen	Hjelmungen	Hjelmungen	Løkkeberge, Halden	Løkkeberge, Halden
Sample name/Description	EPS-plates	7/6-06 EPS-plates	Sandy layer under EPS. Level 2-5cm	Under EPS. '5 cm thick layer representing shift form sand to clay	Sandy layer under EPS. Level 2-10cm	11 m at the side. Silty-sandy approx. 5cm above clay. level 140-145cm
Samping date	11.05.2006	07.06.2006	25.07.2006	25.07.2006	25.07.2006	25.07.2006
Dry Weight (%)	86.5	100	93.8	81.3	94	92.1
Arsen, As (mg/kg DW)	<0.35	<0.30	<0.53	2.6	<0.53	<0.54
Bly, Pb (mg/kg DW)	<2.3	<1.0	5.7	8.2	5.4	4.1
Kadmium, Cd (mg/kg DW)	<0.35	<0.20	0.21	0.23	0.12	0.11
Kobber, Cu (mg/kg DW)	1.2	0.2	12	6.4	12	7.7
Krom, Cr (mg/kg DW)	0.69	0.3	20	17	7	5.4
Kvikksølv, Hg (mg/kg DW)	0.006	0.001	0.11	0.18	0.014	0.011
Nikkel, Ni (mg/kg DW)	0.58	<0.20	13	11	5.7	4.5
Sink, Zn (mg/kg DW)	100	9.3	55	33	27	19
Toluen (mg/kg DW)	0.15	0.005				
PCB 28 (mg/kg DW)	<0.10	<1.0				
PCB 52 (mg/kg DW)	<0.10	<1.0				
PCB 101 (mg/kg DW)	<0.10	<1.0				
PCB 118 (mg/kg DW)	<0.10	<1.0				
PCB 138 (mg/kg DW)	<0.10	<1.0				
PCB 153 (mg/kg DW)	<0.10	<1.0				
PCB 180 (mg/kg DW)	<0.10	<1.0				
1-(3,4-diklorfenyl)-3-meylurea (mg/kg DW)	<0.35	<0.30				
1-(3,4-diklorfenyl)urea (mg/kg DW)	<0.35	<0.30				
1,1,1,2-Tetrakloretan (mg/kg DW)	< 0.005	< 0.005				
1,1,1-Trikloretan (mg/kg DW)	< 0.005	< 0.005				
1,1,2,2-Tetrakloretan (mg/kg DW)	< 0.005					
1,1,2-Trikloretan (mg/kg DW)	< 0.005	< 0.005				
1,1,2-Trikloreten (mg/kg DW)	< 0.005	< 0.005				
1,1-Dikloretan (mg/kg DW)	< 0.005	< 0.005				
1,1-Dikloreten (mg/kg DW)	< 0.005	< 0.005				
1,1-Diklorpropen (mg/kg DW)	< 0.005	< 0.005				
1,2,3-Triklorbensen (mg/kg DW)	< 0.005	< 0.005				
1,2,3-Triklorpropan (mg/kg DW)	< 0.005	< 0.005				
1,2,4-Triklorbensen (mg/kg DW)	<0.12	< 0.005				
1,2,4-Trimetylbensen (mg/kg DW)	0.2	< 0.005				
1,2-Dibrom-3-klorpropen (mg/kg DW)	< 0.005					
1,2-Dibrometan (mg/kg DW)	< 0.005	< 0.005				
1,2-Diklorbensen (mg/kg DW)	< 0.005	< 0.005				
1,2-Dikloretan (mg/kg DW)	< 0.005	< 0.005				
1,2-Diklorpropan (mg/kg DW)	< 0.005	< 0.005				
1,3,5-Trimetylbensen (mg/kg DW)	0.16	< 0.005				
1,3-Diklorbensen (mg/kg DW)	< 0.005	< 0.005				
1,3-Diklorpropan (mg/kg DW)	< 0.005	< 0.005				
1,3-Diklorpropen (mg/kg DW)	< 0.005	< 0.005				
1,4-Diklorbensen (mg/kg DW)	< 0.005	< 0.005				
2,2-Diklorpropan (mg/kg DW)	< 0.005	< 0.005				
2,4,5-T (mg/kg DW)	<0.35	<0.30				
2,4-D (mg/kg DW)	<0.35	<0.30				
2,4-Dinitrotoluen (mg/kg DW)	<0.12	<1.0				
2,6-Dinitrotoluen (mg/kg DW)	<0.12	<1.0				
2-Klornaftalen (mg/kg DW)	<0.12	<1.0				
2-Klortoluen (mg/kg DW)	< 0.005	< 0.005				
4-Bromofenylfenyleter (mg/kg DW)	<0.12	<1.0				
4-Klorfenylfenyleter (mg/kg DW)	<0.12	<1.0				
4-Klortoluen (mg/kg DW)	< 0.005	< 0.005				
Acenaften (mg/kg Ts)	<0.12	<1.0				
Acenaftylen (mg/kg Ts)	<0.12	<1.0				
Alfa-endosulfan (mg/kg DW)	<0.12	<1.0				

Alfa-endosulfan (mg/kg DW)	<0.12	<1.0
Alfa-HCH (mg/kg DW)	<0.12	<1.0
Alifater >C10-C12 (mg/kg Ts)	<0.12	<10
Alifater >C12-C16 (mg/kg Ts)	<0.12	<10
Alifater >C16-C35 (mg/kg Ts)	<0.12	270
Alifater >C8-C10 (mg/kg Ts)	<0.12	<10
Antimon ,Sb (mg/kg DW)		<5.0
Antimon, Sb (mg/kg)		
Antracen (mg/kg Ts)	<0.12	<1.0
Atrazin (mg/kg DW)	<0.35	<0.30
Atrazin-desetyl. (mg/kg DW)	<0.35	<0.30
Atrazin-desisopropyl. (mg/kg DW)	<0.30	<0.30
Azobensen (mg/kg DW)	<0.12	<1.0
BAM. (mg/kg DW)	<0.35	<0.30
Bensen (mg/kg DW)	0.1	0.021
Bensylbutylftalat (mg/kg DW)	<0.12	<1.0
Bentazon. (mg/kg DW)	<0.35	<0.30
Benzo(a)antracen (mg/kg Ts)	<0.12	<1.0
Benzo(a)pyren (mg/kg Ts)	<0.12	<1.0
Benzo(b,k)fluoranten (mg/kg Ts)	<0.12	<1.0
Benzo(g,h,i)perylen (mg/kg Ts)	<0.12	<1.0
Beta-endosulfan (mg/kg DW)	<0.12	<1.0
Beta-HCH (mg/kg DW)	<0.12	<1.0
Bis(2-etylhexyl)ftalat (mg/kg DW)	17	<1.0
Bis(2-kloretoxy)metan (mg/kg DW)	<0.12	<1.0
Bis(2-kloretyl)eter (mg/kg DW)	<0.12	<1.0
Bis(2-kloroisopropyl)eter (mg/kg DW)	<0.12	<1.0
Brom Br (mg/kg DW)	5500	4000
Brombensen (mg/kg DW)	< 0.005	< 0.005
Bromcyclen (µg/kg)	<5	<5
Bromcyclen (µg/kg DW)		
Bromdiklormetan (mg/kg DW)	< 0.005	< 0.005
Bromklormetan (mg/kg DW)	< 0.005	< 0.005
cis-1,2-Dikloreten (mg/kg DW)	< 0.005	< 0.005
Cyanasin. (mg/kg DW)	<0.35	<0.30
Dekabromodiphenylether, PBDE-209 (µg/kg)	<100	<100
Dekabromodiphenylether, PBDE-209 (µg/kg DW)		
Delta-HCH (mg/kg DW)	<0.12	<1.0
Dibenzo(a,h)antrazen (mg/kg Ts)	<0.12	<1.0
Dibromklormetan (mg/kg DW)	< 0.005	< 0.005
Dibrommetan (mg/kg DW)	< 0.005	< 0.005
Dichloprop (mg/kg DW)	<0.35	<0.30
Dieldrin (mg/kg DW)	<0.12	<1.0
Dietylftalat (mg/kg DW)	<0.12	<1.0
Diklormetan (mg/kg DW)	< 0.005	< 0.005
Dimetylftalat (mg/kg DW)	<0.12	<1.0
Di-n-butylftalat (mg/kg DW)	<0.12	<1.0
Di-n-oktylftalat (mg/kg DW)	<0.12	<1.0
Diuron. (mg/kg DW)	<0.35	<0.30
Endosulfansulfat (mg/kg DW)	<0.12	<1.0
Endrin (mg/kg DW)	<0.12	<1.0
Etylbensen (mg/kg DW)	53	0.25
Fenantren (mg/kg Ts)	<0.12	<1.0
Fluoranten (mg/kg Ts)	<0.12	<1.0
Fluoren (mg/kg Ts)	<0.12	<1.0
Fluorotriklormetan (mg/kg DW)	< 0.005	< 0.005
Gamma-HCH (mg/kg DW)	<0.12	<1.0
Heksabrombenzen (µg/kg)	<5	<5
Heksabrombenzen (µg/kg DW)		
Heksabrombifenyl, PBB-153 (µg/kg)	<10	<10
Heksabrombifenyl, PBB-153 (µg/kg DW)	<10	<10
Hexabromocyclododecan (µg/kg)	1260000	6300000
Hexabromocyclododecan, HBCDD (µg/kg DW)	1260000	6300000
'Heksabromodiphenylether, PBDE-138 (µg/kg)	<5	<5
'Heksabromodiphenylether, PBDE-138 (µg/kg DW)	<5	<5
'Heksabromodiphenylether, PBDE-153 (µg/kg)	<20	<20
'Heksabromodiphenylether, PBDE-153 (µg/kg DW)	<20	<20
'Heksabromodiphenylether, PBDE-154 (µg/kg)	<5	<5
'Heksabromodiphenylether, PBDE-154 (µg/kg DW)	<5	<5
Heptabromodiphenylether, PBDE-183 (µg/kg)	<20	<20
Heptabromodiphenylether, PBDE-183 (µg/kg DW)	<20	<20
Heptabromodiphenylether, PBDE-190 (µg/kg)	<100	<100
Heptabromodiphenylether, PBDE-190 (µg/kg DW)	<100	<100
Hexaklorbensen (mg/kg DW)	<0.12	<1.0

Hexaklorbensen (mg/kg DW)	<0.12	<1.0
Hexaklorbutadien (HCBD) (mg/kg DW)	< 0.005	< 0.005
Hexaklorbutadien HBCD (mg/kg DW)	< 0.005	<1.0
Hexakloretan (mg/kg DW)	<0.12	<1.0
Imazapyr (mg/kg DW)	<0.35	<0.30
Indeno(1,2,3-cd)pyren (mg/kg Ts)	<0.12	<1.0
Isophrone (mg/kg DW)	<0.12	<1.0
iso-Propylbensen (mg/kg DW)	3	0
Klorbensen (mg/kg DW)	< 0.005	< 0.005
Krysen (mg/kg Ts)	<0.12	<1.0
Linuron. (mg/kg DW)	<0.35	<0.30
m/p-Xylen (mg/kg DW)	1.5	
MCPA (mg/kg DW)	<0.35	<0.30
Mekoprop (mg/kg DW)	<0.35	<0.30
Monoklorfenol (mg/kg DW)	<0.35	<0.30
Naftalen (mg/kg Ts)	<0.12	<1.0
Naftalen (mg/kg DW)		< 0.005
n-Butylbensen (mg/kg DW)	< 0.005	< 0.005
Nitrobensen (mg/kg DW)	<0.12	<1.0
N-nitrosodifenylamin (mg/kg DW)	<0.12	<1.0
N-nitroso-di-n-propylamin (mg/kg DW)	<0.12	<1.0
o,p-DDE (mg/kg DW)	<0.12	<1.0
o,p-DDT (mg/kg DW)	<0.12	<1.0
Octabromodiphenylether (sum) (µg/kg)	<50	<50
Octabromodiphenylether (sum) (µg/kg DW)		
o-Xylen (mg/kg DW)	1.5	0
p,p-DDE (mg/kg DW)	<0.12	<1.0
p,p-DDT (mg/kg DW)	<0.12	<1.0
Pentabrombifenyl, PBB-101 (µg/kg)	<5	<5
Pentabrombifenyl, PBB-101 (µg/kg DW)	<5	<5
Pentabromodiphenylether (sum) (µg/kg)	<5	<5
Pentabromodiphenylether (sum) (µg/kg DW)	<5	<5
Pentabromodiphenylether, PBDE-100 (µg/kg)	<5	<5
Pentabromodiphenylether, PBDE-100 (µg/kg DW)	<5	<5
Pentabromodiphenylether, PBDE-99 (µg/kg)	<5	<5
Pentabromodiphenylether, PBDE-99 (µg/kg DW)	<5	<5
Pentaklorbensen (mg/kg DW)	<0.12	<1.0
Pentaklorfenol (mg/kg DW)	<0.35	<0.30
p-isoprpyltoluen (mg/kg DW)	< 0.005	
Propylbensen (mg/kg DW)	6.1	0
Pyren (mg/kg Ts)	<0.12	<1.0
sec-Butylbensen (mg/kg DW)	0.38	< 0.005
Simazin (mg/kg DW)	<0.35	<0.30
Summa cancerogena PAH (mg/kg DW)	<0.3	<3.0
Summa diklorfenol (mg/kg DW)	<0.35	<0.30
Summa tetraklorfenol (mg/kg DW)	<0.35	<0.30
Summa triklorfenol (mg/kg DW)	<0.35	<0.30
Terbutylazin (mg/kg DW)	<0.35	<0.30
tert-Butylbensen (mg/kg DW)	0.094	< 0.005
Tetrabrombifenyl, PBB-52 (µg/kg)	<5	<5
Tetrabrombifenyl, PBB-52 (µg/kg DW)	<5	<5
Tetrabrombisfenol A, TBBFA (µg/kg)	<5	<5
Tetrabrombisfenol A, TBBFA (µg/kg DW)	<5	<5
Tetrabromodiphenylether, PBDE-47 (µg/kg)	<5	<5
Tetrabromodiphenylether, PBDE-47 (µg/kg DW)	<5	<5
Tetrakloreten (mg/kg DW)	< 0.005	< 0.005
Tetraklormetan (mg/kg DW)	< 0.005	< 0.005
trans-1,2-Dikloreten (mg/kg DW)	< 0.005	
Tribromodiphenylether, PBDE-28 (µg/kg)	<5	<5
Tribromodiphenylether, PBDE-28 (µg/kg DW)		
Tribrommetan (mg/kg DW)	< 0.005	< 0.005
Triklorbensen (mg/kg DW)	< 0.005	
Triklormetan (mg/kg DW)	< 0.005	< 0.005
Labstatus	Godkjent	Godkjen