SIDS Initial Assessment Report

For

SIAM 25

16-19 October 2007, Helsinki

1. Chemical Name:	Category of Alkyl sulfates, Alkane sulfonates and α-Olefin sulfonates
2. CAS Number:	See Tables 1-1 and 1-2
3. Sponsor Country:	Germany Contact Point: BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) Contact person: Dr. Reiner Arndt Postfach 12 06 29 D-53048 Bonn
4. Shared Partnership with:	SDA / Alkylsulfate Consortium
5. Roles/Responsibilities of the Partners:	
Name of industry sponsor /consortium	SDA / Alkylsulfate Consortium
Process used	The BUA Peer Review Process: see next page
6. Sponsorship History	
How was the chemical or category brought into the SIDS Program?	By ICCA HPV Initiative
7. Review Process Prior to the SIAM:	last literature search (update): 31 August 2006 (Ecotoxicology and Human Health): databases Biosis, Embase, Medline, Toxline, Scisearch; search profile CAS-No. and special search terms
8. Quality check process:	As basis for the SIDS-Dossier the IUCLID was used. All data have been checked and validated by BUA. A final evaluation of the human health part has been performed by the Federal Institute for Risk Assessment (BfR) and of the ecotoxicological part by the Federal Environment Agency (UBA).
9. Date of Submission:	Deadline for circulation: 18 July 2007

10. Date of last Update:

11. Comments:

OECD/ICCA - The BUA* Peer Review Process

Qualified BUA personnel (toxicologists, ecotoxicologists) perform a quality control on the full SIDS dossier submitted by industry. This quality control process follows internal BUA guidelines/instructions for the OECD/ICCA peer review process and includes:

- a full (or update) literature search to verify completeness of data provided by industry in the IUCLID/HEDSET

- Review of data and assessment of the quality of data

- Review of data evaluation

- Check of adequacy of selection process for key studies for OECD endpoints, and, where relevant, for non-OECD endpoints by checking original reports/publications

- Review of key study description according robust summaries requirements; completeness and correctness is checked against original reports/publications
  (if original reports are missing: reliability (4), i.e. reliability not assignable)

- Review of validity of structure-activity relationships

- Review of full SIDS dossier (including SIAR, SIAP and proposal for conclusion and recommendation for further work)

- In case of data gaps, review of testing plan or rationale for not testing

* BUA (GDCh-Beratergremium für Altstoffe): Advisory Committee on Existing Chemicals of the Association of German Chemists (GDCh)

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Abbreviations

AES	Alkyl ether sulfates
ANS	Anionic surfactants
AOS	Alpha-olefin sulfonates
AS	Alkyl sulfates
BCF	Bioconcentration factor
CMC	Critical micelle concentration
HPV	High production volume
MBAS	Methylene blue active substance
PAS	Primary alkane sulfonates
SAS	Secondary alkane sulfonates
SDS	Sodium dodecyl sulfate
TEA	Triethanolamine
WWTP	Waste water treatment plant

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1 IDENTITY

1.1 Identification of the Substances

Three structurally related classes of anionic surfactants are comprised in the ANS category:

Alkyl Sulfates (AS):

Sulfate salts consisting of a predominantly linear **alkyl** chain, bearing a terminal, **sulfate** ester anion, neutralized with a base (HESA, 2003).

e.g. **R-OSO_3^-** cation$^+$ / or amine complex where R = predominantly linear alkyl group

The hydrocarbon chains of alkyl sulfates are either 100 % linear if the parent alcohols are produced from oleochemical feedstocks (fats and oils) or via the Ziegler process by successive condensation of ethylene units or they are predominantly (> 80 %) linear containing a low level of simple branching, typically of the single methyl or ethyl type at the C-2 carbon atom of the alkyl chain if they are derived from the oxo process. Alkyl sulfates derived from oleochemical or Ziegler alcohols have even-numbered alkyl chains; those produced from oxo alcohols contain even- and odd-numbered chains (HERA, 2002; HESA, 2003). The chain length of the category members is in the range of C_8 to C_{18}.

For more detail on the different production processes and the structure of the parent alcohols see Chapter 2.1 on production of alkyl sulfates.

Primary Alkane Sulfonates (PAS):

The salt of a linear saturated **alkyl** chain, bearing a terminal **sulfonate** anion, neutralized with sodium hydroxide (HESA, 2003).

C_x-SO_3^- Na $^+$

The chain length of alkane sulfonates is in the range of C_8 to C_{18}.

Alpha-Olefin Sulfonates (AOS):

A mixture of sodium alkene sulfonate and hydroxy alkane sulfonate salts, with the sulfonate group in the terminal position and the double bond, or hydroxyl group, located at at various positions along a linear aliphatic chain in the vicinity of the sulfonate group (HESA 2003; Ullmann, 2000).

R'-CH(OH)-$(CH_2)_m$-SO_3^- Na^+ where m = 2 or 3

And

R'-CH=CH-$(CH_2)_n$-$SO_3^-Na^+$ where R' = alkyl group and n = 1 - 3

The surfactants are salts or complexes consisting of a hydrophobic hydrocarbon chain (of varying chain length) bearing a terminal, polar, sulfur-containing anion, neutralized with a base-derived cation or an amine (e.g. sodium cation, ammonium cation or triethanolammonium cation).

Alpha-olefin sulfonates are derived from petrochemical C_8 or C_{14-18} α-olefins produced by ethylene oligomerization (HESA, 2003).

The category members are listed in Table 1-1:

Table 1-1: Members of the ANS category

CAS No	Chemical Name (Synonym)	Chemical Shorthand	Surfactant Class *	Molecular Formula	Molecular Weight (g/mol)
Alkyl Sulfates (AS)					
139-96-8	**Sulfuric acid, mono-dodecyl ester, compd. with triethanolamine (1:1)**	**C_{12} ASO_4 TEA**	**AS**	**$C_{18}H_{41}NO_7S$**	**415.59**
142-31-4	**Sulfuric acid, mono-octyl ester, sodium salt**	**C_8 ASO_4 Na**	**AS**	**$C_8H_{17}O_4SNa$**	**232.27**
142-87-0	**Sulfuric acid, mono-decyl ester, sodium salt**	**C_{10} ASO_4 Na**	**AS**	**$C_{10}H_{21}O_4SNa$**	**260.33**
151-21-3	**Sulfuric acid, mono-dodecyl ester, sodium salt**	**C_{12} ASO_4 Na**	**AS**	**$C_{12}H_{25}O_4SNa$**	**288.38**
1072-15-7	n-Nonylsulfate, sodium salt	C_9 ASO_4 Na	AS	$C_9H_{19}O_4SNa$	246.30
1120-01-0	Sulfuric acid, mono-hexadecyl ester, sodium salt	C_{16} ASO_4 Na	AS	$C_{16}H_{33}O_4SNa$	344.49
1120-04-3	Sulfuric acid, mono-octadecyl ester, sodium salt	C_{18} ASO_4 Na	AS	$C_{18}H_{37}O_4SNa$	372.54
1191-50-0	Sulfuric acid, mono-tetradecyl ester, sodium salt	C_{14} ASO_4 Na	AS	$C_{14}H_{29}O_4SNa$	316.43
2235-54-3	**Sulfuric acid, mono-dodecyl ester, ammonium salt**	**C_{12} ASO_4 NH_4**	**AS**	**$C_{12}H_{29}NO_4S$**	**283.43**
3026-63-9	1-Tridecanol, hydrogen sulfate, sodium salt	C_{13} ASO_4 Na	AS	$C_{13}H_{27}O_4SNa$	302.41
4706-78-9	Potassium dodecyl sulfate	C_{12} ASO_4 K	AS	$C_{12}H_{25}O_3SK$	304.49
7065-13-6	Potassium hexadecyl sulfate	C_{16} ASO_4 K	AS	$C_{16}H_{33}O_4SK$	360.59
7739-63-1	Potassium decyl sulfate	C_{10} ASO_4 K	AS	$C_{10}H_{21}O_4SK$	276.43

CAS No	Chemical Name (Synonym)	Chemical Shorthand	Surfactant Class *	Molecular Formula	Molecular Weight (g/mol)
13393-71-0	Sulfuric acid, mono-pentadecyl ester, sodium salt	C_{15} ASO_4 Na	AS	$C_{15}H_{31}O_4SNa$	330.46
39943-70-9	Sulfuric acid, monodecyl ester, compd. with 2,2',2''-nitrilotris[ethanol] (1:1)	C_{10} ASO_4 TEA	AS	$C_{16}H_{37}NO_7S$	387.54
68081-96-9	**Sulfuric acid, mono-C_{10-16}-alkyl esters, ammonium salts**	**C_{10-16} ASO_4 NH_4**	**AS**	**mixture of homologues**	**255.38 - 339.54**
68081-97-0	Sulfuric acid, mono-C_{10-16}-alkyl esters, magnesium salts	C_{10-16} ASO_4 Mg	AS	mixture of homologues	498.98 – 667.30
68081-98-1	**Sulfuric acid, mono-C_{14-18}-alkyl esters, sodium salts**	**C_{14-18} ASO_4 Na**	**AS**	**mixture of homologues**	**316.43 - 372.54**
68585-47-7	**Sulfuric acid, mono-C_{10-16}-alkyl esters, sodium salts**	**C_{10-16} ASO_4 Na**	**AS**	**mixture of homologues**	**260.33 - 344.49**
68611-55-2	Sulfuric acid, mono-C_{10-16}-alkyl esters	C_{10-16} ASO_4	AS	mixture of homologues	Not applicable
68890-70-0	**Sulfuric acid, mono-C_{12-15}-alkyl esters, sodium salts**	**C_{12-15} ASO_4 Na**	**AS**	**mixture of homologues**	**288.38 - 330.46**
68955-19-1	**Sulfuric acid, mono-C_{12-18}-alkyl esters, sodium salts**	**C_{12-18} ASO_4 Na**	**AS**	**mixture of homologues**	**288.38 - 372.54**
68955-20-4	**Sulfuric acid, mono-C_{16-18}-alkyl esters, sodium salts**	**C_{16-18} ASO_4 Na**	**AS**	**mixture of homologues**	**344.49 - 372.54**
73296-89-6	**Sulfuric acid, mono-C_{12-16}-alkyl esters, sodium salts**	**C_{12-16} ASO_4 Na**	**AS**	**mixture of homologues**	**288.38 - 344.49**
85586-07-8	**Sulfuric acid, mono-C_{12-14}-alkyl esters, sodium salts**	**C_{12-14} ASO_4 Na**	**AS**	**mixture of homologues**	**288.38 - 316.43**
85665-45-8	Sulfuric acid, mono-C_{8-14}-alkyl esters, compounds with triethanolamine	C_{8-14} ASO_4 TEA	AS	mixture of homologues	359.48 – 443.64
85681-68-1	Sulfuric acid, mono-(C_{14-18} and C_{16-18} – unsatd.alkyl) esters, sodium salts	C_{14-18} and C_{16-18}= ASO_4 Na	AS	mixture of homologues	316.43 - 372.54
86014-79-1	Sulfuric acid, mono-C_{13-15}-alkyl esters, sodium salts	C_{13-15} ASO_4 Na	AS	mixture of homologues	302.41 - 330.46

CAS No	Chemical Name (Synonym)	Chemical Shorthand	Surfactant Class *	Molecular Formula	Molecular Weight (g/mol)
90583-10-1	Sulfuric acid, mono-C_{8-14}-alkyl esters, ammonium salts	C_{8-14} ASO_4 NH_4	AS	mixture of homologues	227.32 – 311.48
90583-12-3	**Sulfuric acid, mono-C_{12-16}-alkyl esters, ammonium salts**	**C_{12-16} ASO_4 NH_4**	**AS**	**mixture of homologues**	**283.43 - 339.54**
90583-13-4	Sulfuric acid, mono-C_{12-18}-alkyl esters, ammonium salts	C_{12-18} ASO_4 NH_4	AS	mixture of homologues	283.43 – 367.59
90583-16-7	Sulfuric acid, mono-C_{12-14}-alkyl esters, compounds with ethanolamine	C_{12-14} ASO_4 MEA	AS	mixture of homologues	327.48 – 355.54
90583-18-9	**Sulfuric acid, mono-C_{12-14}-alkyl esters, compounds with triethanolamine**	**C_{12-14} ASO_4 TEA**	**AS**	**mixture of homologues**	**415.59 - 443.64**
90583-19-0	Sulfuric acid, mono-C_{8-14}-alkyl esters, lithium salts	C_{8-14} ASO_4 Li	AS	mixture of homologues	216.22 – 300.39
90583-23-6	Sulfuric acid, mono-C_{12-14}-alkyl esters, magnesium salts	C_{12-14} ASO_4 Mg	AS	mixture of homologues	555.09 – 611.20
90583-24-7	**Sulfuric acid, mono-C_{12-18}-alkyl esters, potassium salts**	**C_{12-18} ASO_4 K**	**AS**	**mixture of homologues**	**304.49 - 388.65**
90583-27-0	Sulfuric acid, mono-C_{8-16}-alkyl esters, sodium salts	C_{8-16} ASO_4 Na	AS	mixture of homologues	232.27 – 344.49
90583-31-6	Sulfuric acid, mono-(C_{14-18} and $C_{18-unsaturated}$)-alkyl esters, sodium salts	C_{14-18} and $C_{18=}$ ASO_4 Na	AS	mixture of homologues	316.43 - 372.54
91648-54-3	Sulfuric acid, mono-C_{14-15}-alkyl esters, sodium salts	C_{14-15} ASO_4 Na	AS	mixture of homologues	316.43 – 330.46
91783-22-1	Sulfuric acid, mono-C_{12-13}-alkyl esters, potassium salts	C_{12-13} ASO_4 K	AS	mixture of homologues	304.49 – 318.52
91783-23-2	Sulfuric acid, mono-C_{12-13}-alkyl esters, sodium salts	C_{12-13} ASO_4 Na	AS	mixture of homologues	288.38 – 302.41
96690-75-4	Sulfuric acid, mono-C_{12-14}-alkyl esters, ammonium salts, compds. with triethanolamine	C_{12-14} ASO_4 TEA	AS	mixture of homologues	415.59 – 443.64

CAS No	Chemical Name (Synonym)	Chemical Shorthand	Surfactant Class *	Molecular Formula	Molecular Weight (g/mol)
117875-77-1	**Sulfuric acid, mono-C_{10-16}-alkyl esters, compounds with triethanolamine**	**C_{10-16} ASO_4 TEA**	**AS**	**mixture of homologues**	**387.54 - 471.70**
Not available	Sulfuric acid, mono-C_{15-16}-alkyl esters	C_{15-16} ASO_4	AS	mixture of homologues	330.46 – 344.49
Not available	Sulfuric acid, mono-C_{12-18}-alkyl esters, magnesium salts	C_{12-18} ASO_4 Mg	AS	mixture of homologues	555.09 – 723.41
Not available	Potassium undecyl sulfate	C_{11} ASO_4 K	AS	$C_{11}H_{23}O_4SK$	290.46
Primary Alkane Sulfonates (PAS)					
2386-53-0	Sodium dodecane-1-sulfonate	C_{12} ASO_3 Na	PAS	$C_{12}H_{25}O_3SNa$	272.38
5324-84-5	**1-Octanesulfonic acid, sodium salt**	**C_8 ASO_3Na**	**PAS**	**$C_8H_{17}O_3SNa$**	**216.27**
13419-61-9	Sodium decane-1-sulfonate	C_{10} ASO_3 Na	PAS	$C_{10}H_{21}O_3SNa$	244.33
13893-34-0	Sodium octadecane-1-sulfonate	C_{18} ASO_3 Na	PAS	$C_{18}H_{37}O_3SNa$	356.54
27175-91-3	Sodium tetradecane-1-sulfonate	C_{14} ASO_3 Na	PAS	$C_{14}H_{29}O_3SNa$	300.44
68815-15-6	Sulfonic acids, C15-18-alkane, sodium salts	C_{15-18} ASO_3 Na	PAS	mixture of homologues	314.44 - 356.54
Alpha-Olefin Sulfonates (AOS)					
11067-19-9	Sodium hexadecene-1-sulfonate	C_{16} =/$OHASO_3$ Na	AOS	mixture of homologues	326.47 / 344.49
30965-85-6	Dodecene-1-sulfonic acid, sodium salt	C_{12} =/$OHASO_3$ Na	AOS	mixture of homologues	270.37 / 288.38
68439-57-6	**Sulfonic acids, C_{14-16}-alkane hydroxy and C_{14-16}-alkene, sodium salts**	**C_{14-16} =/$OHASO_3$ Na**	**AOS**	**mixture of homologues**	**298.42 - 344.49**
85536-12-5	Sulfonic acids, C_{12-14}-alkane hydroxy and C_{12-14}-alkene, sodium salts	C_{12-14} =/$OHASO_3$ Na	AOS	mixture of homologues	270.37 – 316.43
91082-14-3	Sulfonic acids, C_{15-18}-alkane hydroxy and C_{15-18}-alkene, sodium salts	C_{15-18} =/$OHASO_3$ Na	AOS	mixture of homologues	312.45 – 372.54
91722-28-0	Sulfonic acids, C_{16-18}-alkane hydroxy and C_{16-18}-alkene, sodium salts	C_{16-18} =/$OHASO_3$ Na	AOS	mixture of homologues	326.47 – 372.54
93686-14-7	**Sulfonic acids, C_{14}-alkane hydroxy and C_{14}-alkene, sodium salts**	**C_{14} =/$OHASO_3$ Na**	**AOS**	**mixture of homologues**	**298.42 - 316.43**

CAS No	Chemical Name (Synonym)	Chemical Shorthand	Surfactant Class *	Molecular Formula	Molecular Weight (g/mol)
863609-89-6	**Sulfonic acids, C_{14-18}-alkane hydroxy and C_{14-18}-alkene, sodium salts**	**C_{14-18} =/$OHASO_3$ Na**	**AOS**	**mixture of homologues**	**298.42 - 372.54**
Not available	Sulfonic acids, $C_{14/16/18}$-alkane hydroxy and $C_{14/16/18}$-alkene, sodium salts (1:1:1)	$C_{14/16/18}$ =/$OHASO_3$ Na	AOS	mixture of homologues	298.42 – 372.54

Bold: HPV chemical
*) AS: Alkyl sulfates; AOS: Alpha-olefine sulfonates; PAS: Primary alkane sulfonates

Some relevant data in the toxicological part were used on compounds with specific chain length but without a defined CAS-number. These are cited under the fictitious CAS-No. 99999-99-9.

The chemicals of this category are predominantly applied in detergents, household cleaning products and cosmetics. Due to their application pattern, they enter the environment in solubilized form via waste water.

1.2 Purity/Impurities/Additives

In commercial products, sodium sulfate and residual alcohols may be present as impurities, due to the production process. The content of sodium sulfate is reported to be max. 1 % resp. 2 % for the products C_{14-16} =/$OHASO_3$ Na (CAS No. 68439-57-6) and C_{12-14} ASO_4 Na (CAS No. 85586-07-8), respectively (Kao Co., 2002a, b). According to Ullmann (2000), fatty alkyl sulfates are generally commercially available as 30 % pastes. Typical data for alkyl sulfates are: active substance 30 - 93 %, sodium sulfate max. 1.0 - 4.0 %, nonsulfated proportion max. 0.5 - 1.8 %, pH 7 - 10.

Typical data for sodium alkane sulfonates from the sulfochlorination process are: active substance 32 - 93 %, disulfonate and polysulfonate 5 - 14 wt %, sodium chloride max. 2.0 - 4.2 wt %, traces of sodium sulfate, neutral oil max. 0.5 - 1.0 wt %, and iron max 5 - 10 ppm. Typical data for sodium alkane sulfonates from the sulfoxidation process are: 30 - 93 %, disulfonate and polysulfonate 4 - 11 wt %, sodium sulfate 2 - 6.5 %, alkane maximum 0.3 - 0.7 %, and APHA color 40 - 50. C_{14-16} and C_{16-18} AOS appear as pale yellow liquid with 37 and 33 % active matter, of which is 3 - 4 wt % disulfonate. Impurities are sodium sulfate 1 wt %, traces of sodium chloride, and unsulfonated substance 1.5 wt % (Ullmann, 2000).

In Table 1-3, the chain length distribution of the products is given, as reported in tests on biodegradation or ecotoxicity (for references cf. IUCLID datasets. When a percentage of active matter is given, the rest is primarily water.

Table 1-2: Composition of the HPV substances of the ANS category

CAS No.	Chemical Shorthand	Composition
139-96-8	C_{12} ASO_4 TEA	single chain length
142-31-4	C_8 ASO_4 Na	single chain length
142-87-0	C_{10} ASO_4 Na	single chain length
151-21-3	C_{12} ASO_4 Na	single chain length
2235-54-3	C_{12} ASO_4 NH_4	single chain length
5324-84-5	C_8 ASO_3 Na	single chain length
68081-96-9	C_{10-16} ASO_4 NH_4	Type A: C_{10} 0 - 1 %, C_{12} 65 - 75 %, C_{14} 22 - 28 %, C_{16} 4 - 8 %Type B: C_{10} 0 - 1 %, C_{12} 60 - 70 %, C_{14} 20 - 30 %, C_{16} 10 - 15 %
68081-98-1	C_{14-18} ASO_4 Na	Type A: C_{16} / $C_{18} \geq 95$ %; C_{12}, C_{14}, C_{20} < 5 % Type B: C_{14} 0 - 1 %, C_{16} 57 - 66 %, C_{18} 32 - 33 %; C_{20} 1 - 9 % Type C: C_{13} + below 1.5 %, C_{14} 11 - 20 %, C_{15} 14 - 23 %, C_{16} 22 % min., C_{17} 38 % min, C_{18} 5 % max, C_{19} 1.4 % max, C_{20} + above 0.10 % max
68439-57-6	C_{14-16} =/$OHASO_3$ Na	Type A: C_{14} 65 %, C_{16} 35 %Type B: C_{14} <80 %, C_{16} <55 % Type C: C_{12} and below 0 - 2 %, C_{14} 60 - 70 %, C_{16} 30 - 40 %, C_{18} and above 0 - 1 %
68585-47-7	C_{10-16} ASO_4 Na	Main chain length: C_{13}Type A: C_{10} 7-9 %, C_{12} 74-77 %, C_{14} 14-17%, C_{16} 0.1-0.5% Type B: C_{10} 0-2 %, C_{12} 40-60 %, C_{13} 20-30 %, C_{14} 5-15% Type C: C_{10} 1 %, C_{12} 65-71 %, C_{14} 22-28 %, C_{16} 4-8 % Type D: C_{10} 10.5 – 11.5 %, C_{12} 53 - 59 %, C_{14} 19 - 24 %, C_{16} 7 – 11 %
68890-70-0	C_{12-15} ASO_4 Na	Type A: C_{12} 18 %, C_{13} 28 %, C_{14} 30 %, C_{15} 20 %Type B: C_{12} 20-25 %, C_{13} 28-33 %, C_{14} 20-25 %, C_{15} 21-28 % Type C: C_{11} and below 0 - 1 %, C_{12} 16 - 26 %, C_{13} 24-34 %, C_{14} 20 - 30 %, C_{15} 20 - 30 %, C_{16} and above 0 – 1 %
68955-19-1	C_{12-18} ASO_4 Na	C_{12} 48 - 58 %, C_{14} 18 - 24 %, C_{16} 8 - 12 %, C_{18} 11 - 15 %
68955-20-4	C_{16-18} ASO_4 Na	C_{14}: 3 - 7 %, C_{16}: 25 - 35 %, C_{18}: 60 - 67 %
73296-89-6	C_{12-16} ASO_4 Na	Type A: C_{12} 60 - 66 %, C_{14} 21 - 25 %, C_{16} 10 - 12 %Type B: C_{12} 4-6 %, C_{13} 6-7 %, C_{14} 80-88 %, C_{15} 4-6 %, C_{16} 0 – 0.5 %
85586-07-8	C_{12-14} ASO_4 Na	C_{10} max. 1.5 %, C_{12} 51 - 57 %, C_{14} 41 - 47 %, C_{16} max. 1.5 %
90583-12-3	C_{12-16} ASO_4 NH_4	Type A: C_{12} / C_{13} / C_{14} / C_{15} > 95 %; C_{10} / C_{17} < 5 % Type B: C_{12} / C_{14} > 80 %; C_{16} < 20 %; C_8, C_{10}, C_{18} < 5 % Type C: C_{12} < 10 %; C_{14} / C_{16} > 90 %; C_{10}, C_{18} < 5 % Type D: C_{12} 70 %; C_{14} 25 %, C_{16} 5 %
90583-18-9	C_{12-14} ASO_4 TEA	C_{12} 70 %, C_{14} 25 %, C_{16} 5 %

CAS No.	Chemical Shorthand	Composition
90583-24-7	C_{12-18} ASO_4 K	Type A: C_{12} / C_{14} > 50 %; C_{16} / C_{18} > 10 %; C_8, C_{10}, C_{20} < 5 % Type B: C_{12} / C_{14} > 10 %; C_{16} / C_{18} > 60 %; C_{20} < 5 %
93686-14-7	C_{14} =/$OHASO_3$ Na	single chain length: alkene sulfonate 50 %, hydroxy alkane sulfonate 50 %
117875-77-1	C_{10-16} ASO_4 TEA	C_{10} 0 - 1 %, C_{12} 65 - 75 %, C_{14} 22 - 28 %, C_{16} 4 - 8 %
863609-89-6	C_{14-18} =/$OHASO_3$ Na	C_{14} 69 %, C_{16} 14 %, C_{18} 17 %; alkenyl 70 %, hydroxyl 30 %

1.3 Physico-Chemical properties

Commercial substances of the ANS category are marketed as different physical states, like powders, granules, needles, pastes, and aqueous solutions. Aqueous preparations contain varying amounts of water (pastes, solutions). The properties mentioned in this chapter refer to the anhydrous substances.

Surfactant properties

Properties specific for surfactants are surface tension, critical micelle concentration or Krafft point.

Critical micelle concentration (CMC): There is a relatively small range of concentrations separating the limit below which virtually no micelles are detected and the limit above which virtually all additional surfactant molecules form micelles. Many properties of surfactant solutions, if plotted against the concentration, appear to change at a different rate above and below this range. By extrapolating the loci of such a property above and below this range until they intersect, a value may be obtained known as the critical micellization concentration (critical micelle concentration), symbol CM, abbreviation CMC (or c.m.c.). As values obtained using different properties are not quite identical, the method by which the CMC is determined should be clearly stated (IUPAC Compendium, 2004).

Krafft point: The temperature (more precisely, narrow temperature range) above which the solubility of a surfactant rises sharply. At this temperature the solubility of the surfactant becomes equal to the critical micelle concentration. It is best determined by locating the abrupt change in slope of a graph of the logarithm of the solubility against t or 1/T (IUPAC Compendium, 2004).

Experimental data of alkyl sulfates with discrete chain length are listed in Table 1-4. For linear alkyl sulfates, CMC decreases with chain length, while Krafft temperature increases.

Table 1-3

: Surfactant properties for some alkyl sulfates (for references cf. IUCLID datasets)

CAS No.	Chemical Shorthand	**Surface tension (mN/m) at 20 °C**	**CMC (mM) in water at 20 °C**	**Krafft point (°C)**
139-96-8	**C_{12} ASO_4 TEA**	**49 at 100 mg/l** [2)]	**5.91 / 5.50** [2)]	**< -5**
142-31-4	**C_8 ASO_4 Na**		**130 / 134**	
142-87-0	**C_{10} ASO_4 Na**	**33 at 100 mg/l** [2)]	**33.5**	**8** [1)]
151-21-3	**C_{12} ASO_4 Na**	**42.6 at 0.1 %** **55.9 at 100 mg/l**	**8.0 - 8.4** [2)]	**16 / 17**
1191-50-0	C_{14} ASO_4 Na	35.2 at 1 vol%[2)]	2.21	36[1)]
1120-01-0	C_{16} ASO_4 Na	35 at 0.1 vol% [2)]	0.55 [2)]	44 / 45
1120-04-3	C_{18} ASO_4 Na	36.0 at 1 vol%	0.16 [3)]	54 / 56
2235-54-3	**C_{12} ASO_4 NH_4**	**38 at 100 mg/l** [2)]		
39943-70-9	C_{10} ASO_4 TEA	11.8 [2)]	11.3 [2)]	

Bold: HPV chemical 1) no concentration data 2) at 25 °C 3) at 40 °C

The data listed in the table above were obtained in distilled water. Surfactants show increased surface activity in hard water compared to distilled water. The increased activity can be attributed to the presence of electrolytes, especially Ca^{2+} and Mg^{2+}. Rosen et al. (1996) found that the anionic surfactants showed smaller CMC values in hard river water than in distilled water, indicating that micellization is facilitated in hard water.

Weil et al. (1963) estimated CMCs and Krafft points for a series of alkane sulfonates. While the CMCs decreased from 6.9 to 0.21 mmol/l at carbon chain lengths from C_{10} to C_{17}, the Krafft point increases from 38 °C to 62 °C. They also estimated Krafft points for sodium 1-hydroxy-2-alkane sulfonates as 59 - 93 °C and CMCs for 1-hydroxy-2-alkane sulfonic acids as 0.35 - 0.0078 mmol/l for carbon chain lengths from C_{12} to C_{18}.

Data about surface tension, CMC and Krafft points for α-olefin sulfonates were not found in the literature.

Physico-chemical properties of the HPV-Substances with single chain length are listed in Table 1-4 (for references see IUCLID datasheets). It is briefly discussed how each property varies as a function of alkyl chain length and counter-ion. Estimated properties in this section are obtained using EPI Suite v. 3.12 (2005).

Many category members are composed of more than one discrete chain length component. The relative amounts of the homologues reflect the source from which the raw materials are derived (plant or animal fats and oils) or are the result of the manufacturing processes of the parent alcohols or of intentional blending of raw materials. Property estimates are for a discrete chain length, while a property of a commercial product is a function of that property for each of the

discrete components. Values for homologues with discrete chain length are listed in Annex II Tables II-1 to II-4.

Alteration of the counter-ion considerably influences the physico-chemical properties of undissociated substances. Under environmental conditions the surfactant will dissociate and the influence of the counter -ion will vanish.

All calculated physico-chemical properties of surfactants should be treated with caution, because the estimation models do not take into account surfactant properties. This is attributed to the inherent limitations of the algorithms with surface active materials. In addition, the calculated results are doubtful for ionic substances, e. g. anionic surfactants with their counter ions.

In Table 1-4, physico-chemical data of HPV substances with single chain length are presented. Where no experimental data were available, values calculated by EPI Suite v. 3.12 (2005) are included. Technical mixtures can be characterized by a range defined by the shortest and longest homologue present. For further calculated values cf. Annex II.

Melting points

Few measured values are reported for **alkyl sulfates, sodium salts** in the literature; those that are available indicate that the melting points for this sub-category are fairly constant regardless of chain length. Measured melting points are in the range of 181°C (C_8) to 193°C (C16). Calculated melting points for chain lengths from 8 to 16 are in the range of 232 to 286 °C (EPI Suite v. 3.12, 2005). However, the calculated melting points are depending on the counter-ion. Melting points of ammonium salts are 36 °C lower, magnesium salts and TEA salts 40-70 °C higher relative to sodium salts. Melting points of potassium salts are approximating the sodium salts. (See Annex II, Table II-1). Experimental values for TEA salts with chain lengths from 10 to 18 are much lower, they were measured in the range of 64 - 87 °C (Badwan et al., 1980).

Experimental data for **alkane sulfonates** are not available. Calculated values are similar to alkyl sulfates, sodium salts (227 and 281 °C for the C_8 and C_{18} homologue). Calculated values for **alkene** and **hydroxyalkane sulfonates** are slightly higher (cf. Annex II).

Boiling points

Experimentally determined boiling points for any of the ANS surfactants were not identified. Values, estimated using EPI Suite v. 3.12 (2005), are quite high, e.g. 542°C to 658°C for alkyl sulfates, sodium salts. These estimates are of no practical relevance since **linear alkyl sulfates, alkane sulfonates** and **α-olefin sulfonates**, like most other organic salts, decompose before they reach their theoretical boiling points. Alkyl sulfates decompose at high temperature. At 100 °C they lose any associated water and at 150 °C thermal decomposition begins. The organic part of the molecule is completely decomposed at 285 °C (Domingo, 1996).

Table 1-4: Summary of physico-chemical properties of HPV chemicals with single chain length

CAS No.	Chemical Shorthand	Surfactant class	Melting point (°C)	Boiling point (°C)	Density (g/cm^3 at 20 °C)	Vapor pressure (hPa at 25 °C)	Water solubility (mg/l at 25 °C)	Log K_{OW}	Henry's law constant ($Pa \cdot m^3/mol$)
139-96-8	**C_{12} ASO_4 TEA**	AS	72 - 122.5 (exp) 310 [1)]	709 [1)]	ca. 1 / 1.1	$1.3 \cdot 10^{-21}$ (1)	Miscible (exp) 16 [1)]	2.55 [1]	$6.1 \cdot 10^{-17}$ (1, 2)
142-31-4	**C_8 ASO_4 Na**	AS	181-183(exp) 232 [1)]	542 [1)]	-.	$1.8 \cdot 10^{-11}$ (1)	50 570 [1)]	-0.27 [1] / 0.6 (calc.)	$6.0 \cdot 10^{-3}$ (1, 2)
142-87-0	**C_{10} ASO_4 Na**	AS	ca. 197 (exp) 243 [1)]	565 [1)]	-	$3.4 \cdot 10^{-12}$ (1)	5 133 [1)]	0.71 [1] / ca. 1.1 (calc.)	$1.1 \cdot 10^{-2}$ (1, 2)
151-21-3	**C_{12} ASO_4 Na**	AS	ca. 193 - 207 (exp) 254 [1)]	589 [1)]	>1.11	$2.4 \cdot 10^{-12}$ (1)	196 000 at 20 °C / 617 [1)]	1.6	$1.9 \cdot 10^{-2}$ (1, 2)
2235-54-3	**C_{12} ASO_4 NH_4**	AS	218 [1)]	512 [1)]	-	$1.6 \cdot 10^{-10}$ (1)	18 [1)].	3.42 [1]	$8.9 \cdot 10^{-11}$ (1, 2)
5324-84-5	**C_8 ASO_3 Na**	PAS	227 [1)]	530 [1)]	-	$4.33 \cdot 10^{-11}$ (1)	308 000 [1)]	-0.7 (exp) -1.09 [1]	$9.3 \cdot 10^{-3}$ (1, 2)

*: FAS: Fatty alkyl sulfates; AOS: Alpha-olefine sulfonates
Values without indices are experimentally determined, for references see IUCLID datasets
[1]) value calculated by EPI Suite v. 3.12 (2005)
[2]) bond method

Octanol/water partition coefficients (K_{OW})

Experimentally derived octanol/water partition coefficients (K_{OW}) for these surfactants are also very scarce in the literature. This is most likely attributable to the fact that the accurate determination of an octanol/water partition coefficient is very difficult. Surfactants will concentrate at the interface and bridge the interface with the hydrophobic tail in the solvent and the hydrophilic head in the water, i.e. surfactants will exist in both phases. The accurate measurement of a K_{OW} for a surfactant requires a special apparatus in which the surface of that boundary is minimised.

The KOWWIN v. 1.67 program (EPI Suite v. 3.12, 2005) provides estimates for the octanol/water partition coefficient (K_{OW}), increasing with chain length. Linear **alkyl sulfate,** sodium salts (chain length 8-18) exhibit calculated log K_{OW} values of –0.27 to 4.64. The measured log K_{OW} value of 1.6 for C_{12} ASO_4 Na (Hansch, Leo, and Hoekman, 1995) corresponds to the estimated value of 1.69.

Measured log K_{OW} values for **alkane sulfonate,** sodium salts are lower than the corresponding values for alkyl sulfates, they were estimated to be in the range of -0.7 (C_8) to 0.7 (C_{14}) (Sanchez-Leal et al., 1991). Calculated values for C_8 to C_{18} are between -1.09 and 3.82.

For **alkene sulfonate**, sodium salts (chain length 12 - 18) calculated log K_{OW} are lower by an amount of ca. 1 (0.66 - 3.60) and values for **hydroxy alkyl sulfonates**, sodium salts (chain length 14 - 16) are lower by > 2 than for linear alkyl sulfates, sodium salts.

Estimated log K_{OW} values are influenced by the counter-ion, however, this is only true for the undissociated molecule. Since alkyl sulfates, alkane sulfonates, and α-olefin sulfonates are salts and dissociate in water, the influence of the counter-ion is of no relevance. Therefore calculated log K_{OW} values should be treated with caution.

K_{OW} depends on pH, concentration, and many other factors that may vary greatly under realistic conditions. Surfactants have a tendency to concentrate at hydrophilic/hydrophobic boundaries rather than to equilibrate between phases. Therefore, K_{OW} is not a good descriptor of surfactant hydrophobicity and only of limited predictive value for the partitioning of these compounds in the environment.

Vapor pressure

No reported experimental values for vapor pressure were found in the literature. The reason is the ionic character of the substances of this category. Vapor pressure of salts is extremely low, in other words these surfactants are essentially non volatile and their vapor pressures are very difficult to measure. Theoretically, the vapor pressure should decrease as the alkyl chain length increases.

The estimated values for vapor pressure (EPI Suite v. 3.12, 2005) for linear **alkyl sulfates** (sodium salts, chain length 8-18) are in the range of 10^{-11} to 10^{-15} hPa. Calculated values decrease with chain length and are influenced by the counter-ion. Replacing sodium by TEA or magnesium lowers the estimated vapor pressure, replacing sodium by ammonium increases the calculated value (for details cf. Annex II).

For **alkane sulfonate** (C_8 and C_{18}), sodium salts vapor pressure values of $4.3 \cdot 10^{-11}$ and $9 \cdot 10^{-15}$ hPa were calculated, values were between $2.1 \cdot 10^{-13}$ and $6.9 \cdot 10^{-15}$ hPa for **alkene sulfonates** (chain length 14-18) and between $3.3 \cdot 10^{-17}$ and $5.8 \cdot 10^{-19}$ hPa for **hydroxy alkane sulfonates** (chain length 14-18).

Consequently speaking, these chemicals are also, because of ionic structure and formation of micelles, not volatile and hence they will not partition to the atmosphere.

Water solubility

When surface-active substances are dispersed in water, they partially (depending on the solubility) dissolve, i.e. in solution they exist as hydrated molecules. At higher concentrations, micelles are formed. Data about the critical micelle concentration (CMC; cf. Table 1-4) are in some way also data on water solubility. Above the CMC the surfactant molecules partition into micelles while the concentration of individual surfactant molecules in solution remains constant. This phenomenon is not always considered by the reported experimental data. Finely dispersed material (e.g. micelles) is often not distinguished from material that is really in solution (molecular disperse).

Experimental values for water solubility are reported only for some **alkyl sulfates**. The calculated solubility values decrease by approximately one order of magnitude for every two carbons added to the alkyl chain. However, measured values for alkyl sulfates, sodium salts are (approx. 50 to 300 fold) higher than the calculated data. Calculation seems to significantly underestimate water solubilities of alkyl sulfates. Dyer et al. (1997) experimentally determined the solubility of alkyl sulfates in moderately hard reconstituted water (114 - 205 mg/l $CaCO_3$). Calcium salts of alkyl sulfates have a reduced solubility in water, therefore the values are lower than in distilled water (see Table 1-6).

Much like the K_{OW}, the estimates of the WSKOW Version 1.41 program (EPI Suite v. 3.12, 2005) are of limited practical use for this category, because micelle formation above the critical micelle concentration is not taken into account by the estimation program.

Table 1-5

: Estimated (EPI Suite v. 3.12, 2005) and experimentally derived solubilities of single chain alkyl sulfates, sodium salts in distilled and reconstituted water

CAS No.	Chemical shorthand	Calc. water solubility (mg/l)	Exp. solubility in distilled water (mg/l)	Reference	Exp. solubility in reconstituted water (mg/l) (Dyer et al., 1997)
142-31-4	**C_8 ASO_4 Na**	**50 570**			
142-87-0	**C_{10} ASO_4 Na**	**5133**			
151-21-3	**C_{12} ASO_4 Na**	**617**	**196 000 (20 °C)**	**Dreger et al. (1944)**	
1191-50-0	C_{14} ASO_4 Na	51	2 370 (25 °C)	Dreger et al. (1944)	5.13
13393-71-0	C_{15} ASO_4 Na	16			0.4
1120-01-0	C_{16} ASO_4 Na	5.0	300 (30 °C)	Dreger et al. (1944)	0.08
1120-04-3	C_{18} ASO_4 Na	0.49		Dyer et al. (1997)	insoluble

Bold: HPV chemical

Apart from this, some qualitative rules can be deduced from calculations. Calculated water solubility of sodium salts of **alkane sulfonates** (C_8 and C_{18}) is about a factor of 6 higher than for the corresponding **alkyl sulfates** (308 000 and 3.09 mg/l; see Annex II, Table II-2), while the calculated values for **alkene sulfonate** (chain length 12 - 18), sodium salts and **hydroxy alkane sulfonate**, sodium salts (chain length 14 - 18) are higher by factors of approx. 8-9 and 100 (4.9 - 4 982 mg/l and 51 - 5 268 mg/l, respectively). Particularly, the presence of a hydroxyl group enhances water solubility (see Annex II Tables II-3 and II-4).

Calculated water solubility is influenced by the counter-ion (see Annex II Table II-1): Values for linear alkyl sulfates, sodium salts (chain length 10-16) are in the range of 5.0 - 5 133 mg/l, for the corresponding ammonium salts the calculated water solubility is lower (0.18 - 182 mg/l) and very similar to that of compounds with TEA (0.15 - 168 mg/l). For magnesium salts it is considerably lower ($3.7 \cdot 10^{-12}$ - $5.1 \cdot 10^{-6}$ mg/l). Under environmentally relevant conditions, however, soluble substances (i.e. with a chain length of <16) will dissociate in the presence of water and the original cation is no longer related to the original alkylsulfate unit, so that the counter-ion is of no relevance any more.

Since the critical micelle concentration (CMC) is defined as the concentration where surfactant monomers start to form micelles, the CMC can be regarded as the maximum solubility of monomers. Measured CMC values are reported in a comprehensive compilation of published CMC data (van Os et al., 1993). In table 1-7 CMC values for individual chain lengths of alkyl sulfates and alkane sulfonates spanning the range of the category chemicals are listed. These concentrations have been determined by measurement of electrical conductivity. There is a clear correlation between chain length and CMC both for alkyl sulfates and alkane sulfonates: CMC as a measure of water solubility decreases from shorter to longer chain lengths by a factor of 3-4 for every CH_2-unit.

Table 1-6: Critical micelle concentrations (CMC) of sodium alkyl sulfates and alkane sulfonates in water at 25 °C (van Os et al., 1993).

	Alkyl sulfates			**Alkane sulfonates**		
Chain length	CAS number	mmol/L	mg/L	CAS number	mmol/L	mg/L
C_8	**142-31-4**	**130.2**	**30241.6**	**5324-84-5**	**155.0**	**33521.9**
C_{10}	**142-87-0**	**33.0**	**8590.9**	13419-61-9	38.1[a]	9309.0
C_{12}	**151-21-3**	**8.2**	**2364.7**	2386-53-0	11.0[b]	2996.2
C_{14}	1191-50-0	2.1	648.7	27175-91-3	2.5[b]	751.1
C_{16}	1120-01-0	0.45[a]	155.0	15015-81-3	0.74[b]	243.1
C_{18}	1120-04-3	0.16[b]	59.6			

Bold: HPV chemical
[a] 30 °C [b] 40 °C

Dissociation constant

Salts of strong acids are completely dissociated in aquatic compartments. Under environmental conditions the chemicals of this category are completely dissociated. Although this is only a qualitative indication of the pKa, it is adequate information for the environmental hazard assessment.

1.4 Category Justification

The most important common structural feature of the category members is the presence of a predominantly linear aliphatic hydrocarbon chain with a polar sulfate or sulfonate group, neutralized with a counter ion (i.e., Na^+, K^+, NH_4^+, or an alkanolamine cation).

The hydrophobic hydrocarbon chain (with a length between C_8 and C_{18}) and the polar sulfate or sulfonate groups confer surfactant properties and enable the commercial use of these substances as anionic surfactants. The close structural similarities result in physico-chemical properties and environmental fate characteristics which follow a regular pattern. Common physical and/or biological pathways result in structurally similar breakdown products, and are, together with the surfactant properties, responsible for similar environmental behavior and essentially identical hazard profiles with regard to human health. The structural similarities result in the same mode of ecotoxic action. Within each subcategory the most important parameter influencing ecotoxicity is the varying length of the alkyl chain. Although the counter ion may also influence the physico-chemical behavior of these chemicals, the chemical reactivity and classification for the purpose of this assessment is not expected to be affected by the difference in counter ion. Several of the counter-ions have also been assessed in the OECD HPV Programme: triethanolamine (CAS 102-71-6), the ammonia category (CAS 7664-41-7; 1336-21-6; 7783-18-8; 12593-60-1) and ammonium salts, like ammonium sulfate (CAS 7783-20-2), chloride (CAS 12125-02-9) and bicarbonate (CAS 1066-33-7).

This category includes three structurally related classes of anionic surfactants (ANS). The category surfactants are all salts or complexes consisting of a **hydrophobic, hydrocarbon chain** (of varying chain length) bearing a **terminal, polar, sulfur-containing anion**, neutralized with a **base-derived cation or an amine** (e.g. sodium cation, ammonium cation, or triethanolamine). Whereas in alkyl sulfates the aliphatic hydrocarbon chain is linked to the sulfur residue via a C-O-S bond, alkane sulfonates and α-olefin sulfonates possess a C-S bond. Alkyl sulfates are highly susceptible to hydrolysis under acidic and alkaline conditions, whereas the sulfonates are remarkably stable. Under environmental conditions, both alkyl sulfates and the sulfonates are stable.

Alkyl Sulfates (AS):	Sulfate salts consisting of a predominantly linear alkyl chain, bearing a terminal, sulfate ester anion, neutralized with a base; single chain length or a defined chain length distribution
Primary Alkane Sulfonate (PAS):	The salt of a linear saturated alkyl chain, bearing a terminal sulfonate anion, neutralized with sodium hydroxide
Alpha Olefin Sulfonate (AOS):	A mixture of sodium alkene sulfonate and hydroxyl alkane sulfonate salts, with the sulfonate group in the terminal position and the double bond, or hydroxyl group, located at a position along a linear aliphatic chain in the vicinity of the sulfonate group

The most important **structural feature**, the presence of an aliphatic hydrocarbon chain bearing a polar, anionic terminus, confers surfactant properties. Surfactant properties play a central role for the environmental fate and behavior as well as for the (eco)toxicity of these materials.

Many of the category members are **mixtures composed of single chain length components (homologues)**. Property estimates are for a discrete chain length. This is because the estimation technique is based on a relationship between a specific chemical structure and a measured or estimated property of that structure. A property of a commercial mixture of linear alkyl sulfates or sulfonates is therefore a function of that property for each of the discrete chain length components in the mixture.

The **physical-chemical properties** of the surfactants in this category are closely correlated with their structural properties, especially the alkyl chain length. The obligatory endpoints for assessing the environmental fate and behavior (melting point, boiling point, log K_{OW}, water solubility, vapor pressure) as well as the hazard of the ANS sub-categories are sufficiently covered by the available (measured and calculated) data.

Concerning **environmental fate and pathways** all of the surfactants in this category are essentially non-volatile, which implies that atmospheric photodegradation is irrelevant for hazard assessment. Furthermore, they are stable to hydrolysis under environmental conditions.

In view of the great differences in water solubility, one would expect differences in environmental distribution. However, it has to be kept in mind that as a result of the applications in household cleaning products, detergents and cosmetics, the surfactants of this category enter the environment primarily via the wastewater and do not partition into the atmosphere. Environmental distribution will therefore be confined to the water and sediment compartments. Monitoring studies revealed low concentrations in surface waters for alkyl sulfates and α–olefin sulfonates of chain lengths > C_{12} and low sediment concentrations for alkyl sulfates, indicating rapid biodegradation in the aquatic compartment and no accumulation in sediment (see below).

Experimentally derived partition coefficients for soil/sediment-water are available for alkyl sulfates (but not for alkane sulfonates and α-olefin sulfonates) with chain lengths from C_8 to C_{14}, indicating increased adsorption when chain length increases. EPI Suite calculations on K_{OC} resulted in significantly higher values (more than 1 order of magnitude). These calculations should be handled and used with care. However, because of the common sorption mechanism (mainly hydrophobic interactions due to the alkyl chains, no ionic interactions by the functional groups) sorption of the alkene sulfonates is expected to be in the same range as for the alkane sulfates. Sorption of AOS is expected to be lower than of alkyl sulfates because of the higher polarity due to the hydroxyl group. **Consequently, the available data about adsorption are supposed to be sufficient for the environmental hazard assessment**.

Surfactants of all three sub-categories are rapidly and completely biodegraded in sewage treatment under aerobic conditions.

Under anoxic conditions, sulfates have been shown to mineralize, however, for the sulfonated surfactants, the weight of the evidence suggests that these do not (or only very slowly) biodegrade anaerobically, due to the recalcitrance of the C-S bond. After all, the actual effective removal of the anionic surfactants is reflected by the low concentrations measured for AS and also for AOS in different surface waters and receiving waters. **The available and reliable data are considered to adequately cover the SIDS endpoint biodegradation and support a conclusion of rapid biodegradability for the entire range of substances in the three sub-categories.**

Experimental data show that the bioaccumulation potential of alkyl sulfates in aquatic species is low at carbon chain lengths up to C_{16} (c.f. chapter 2.2.6). The chemistry and physical properties of alkane sulfonates and α-olefin sulfonates are similar to AS. **Hence, the bioconcentration tendency for AOS and alkane sulfonates is expected to be similar to those of the AS**.

The **aquatic toxicity** of the category compounds is influenced by a number of parameters, the **length of the alkyl chain** being obviously most important, whereas for the counter-ion no significant influence was observed. Several studies on fish and *Daphnia* (being the most sensitive aquatic organisms), conducted under comparable experimental design, demonstrate increasing toxicity for chain lengths up to C_{14}. **This was observed in available tests for all three subcategories**. At higher chain lengths, the picture becomes inconsistent, at least for (acute) fish/*Daphnia* toxicity of the **AS** subcategory. Around C_{16} water solubility becomes the limiting factor for toxicity and, depending on the test substance, preparation of the test solutions leads to smaller or bigger micelles with differing bioavailability. Intrinsic toxicity and physical effects interfere with each other, resulting in the observed variation of ecotoxicity results. While in some test series toxicity strongly decreases up to C_{18}, other studies show increasing toxicity up to $C_{16\text{-}18}$. The **PAS** and the **AOS** subcategories include less substances. Thus, a chain length dependency of toxic effects, particularly for **PAS,** can only be indicated. For the **PAS**-subcategory acute toxicity data are available for *Daphnia magna*, but not for fish and algae. The acute toxicity of **PAS** to *Daphnia* is comparable to **AS** in the range between C_8 and C_{10}, while C_{12} and C_{14} are significantly less toxic. Taking into account the similar environmental fate and behavior as well as the similar mode of ecotoxic action, the missing effect data on fish and algae for **PAS** (at least the C_8-sulfonate) should adequately be covered by results available for the **AS** subcategory.

As far as the **AOS** subcategory is concerned, data on all acute aquatic endpoints recommended by OECD are available. Like for the **PAS**, only a limited chain length distribution was tested ($>C_{12}/C_{14}$), however, most of the available results are reliable (guideline studies) and - most important - the critical chain lengths are covered. For the most sensitive trophic level (fish/*Daphnia*), the response pattern is only partly comparable to **AS.** While available acute fish toxicity values determined for $C_{12\text{-}14}$ **AOS** are comparable to **AS** data, **AOS** seem to be more toxic than AS at higher chain lengths (C_{16} and longer). In contrast to **AS**, there is no indication, that the toxicity of **AOS** may decrease at higher chain lengths. Whereas the effects of **AOS** on daphnids are comparable to **AS** data for the C_{14} chain length, results for chain lengths >14 cannot be compared with **AS** values, due to the observed scattering of results with higher homologues of **AS**.

See also detailed description in Annex I.

The **toxicological profile** of the alkyl sulfates and the olefin sulfonates reveals many similarities. For all compounds the acute oral toxicity as well as repeated oral toxicity is low. After multiple oral dosing, the gastrointestinal tract (dosing via gavage), and the liver were identified as target

organs. The similarity between both subgroups is evident also for other endpoints such as skin and eye irritation, sensitization, mutagenicity, carcinogenicity and reproductive and developmental toxicity.

The database for the alkyl sulfonates is very limited. These substances are in between the two other groups, as they share the saturated alkyl chain with the alkyl sulfates and the sulfonic acid group with the olefin sulfonates. As for the alkyl sulfates and olefin sulfonates, the acute oral toxicity is low. If data from the olefin sulfonates are taken into account, it can be assumed that the alkyl sulfonates also will cause skin and eye irritation, but not have sensitizing or genotoxic effects. Longer-term studies as well as data concerning carcinogenicity or reproduction toxicity are missing. However, based on metabolism studies it can be concluded that the properties of the alkyl sulfates and sulfonates are similar.

Alkyl sulfates

For the alkyl sulfates, various studies with information are available for each SIDS endpoint. The database includes compounds of different chain lengths (C_{8}-$_{18}$, even and odd numbered) as well as different counter ions.
All alkyl sulfates show a very similar oral absorption, excretion and metabolites profile. Butyric acid-4-sulfate and sulfate are the main metabolites irrespective of chain length for the even numbered alkyl sulfates and propionic acid-3 sulfate, pentanoic acid-5-sulfate and sulfate are the main metabolites for the odd numbered alkyl sulfates. Compared to compounds with other chain lengths, for $C_{12}ASO_4$ a higher oral absorption and faster metabolism/excretion was observed. The acute oral toxicity for most compounds is relatively low and only unspecific signs of intoxication were observed. In longer-term studies all compounds showed a strikingly similar pattern of effects with the liver as the only target organ and with similar NOAEL and LOAEL ranges. There was no difference between mixtures with even or odd chain lengths. In Ames tests with various different mixtures as well as with eukaryotic test systems consistently negative results were obtained. The database on genotoxicity is considered as sufficient, as several *in vivo* studies with compounds of different chain lengths are available, i.e. micronucleus test and chromosome aberration test. Apart from one exception - a chromosome aberration assay with hamsters - all other studies gave negative results. There are also oral carcinogenicity studies on several mixtures available, which all were negative.

Effects of counter ions

In aqueous environments the salts will dissociate, so that the counter ions will not fundamentally alter pathways of tissue disposition, metabolism, excretion, or target organs of toxicity. Accordingly no major differences were found in most of the endpoints between the compounds with different counter ions. Furthermore this is consistent with the low toxicity of the counter ions (see reviews for monoethanolamine [BUA, 1996[1]], triethanolamine [BG Chemie, 1990[2]] or ammonia [ATSDR, 2004[3]]). However, the irritancy is influenced by the counter ion, as TEA seems to reduce the skin irritating properties of the compounds compared with sodium, magnesium or ammonium.

[1] BUA (1996) Monoethanolamin. BUA-Report No. 202 (summary is attached)
[2] BG Chemie (1990) Toxicological Evaluation of 102-71-6 Triethanolamin (BG No. 57)
[3] ATSDR (2004) Toxicological Profile for Ammonia

Alkane sulfonates

Data for nearly all endpoints are missing. However, the sulfonates in general have been subject of a category approach of the German BUA (Greim et al., 1994[4]). It shows similarities for all members of the group irrespective of their structure. They are quickly eliminated, the acute and repeated dose toxicity is low, there was no indication for genotoxic effects and the results of teratogenicity studies were negative. This is in compliance with data obtained for the alkyl sulfates and α-olefin sulfonates. Based on the available data, the similar toxicokinetic properties and a comparable metabolism of the alkyl sulfates and alkane sulfonates, adverse effects on reproduction and development are not to be expected at doses which do not induce parental toxicity.

α-**Olefin sulfonates**

For the olefin sulfonates several studies are available and all SIDS endpoints are covered. The chain lengths investigated cover C_{14-18} with sodium as counter ion. The observed effects are very similar compared with the alkyl sulfates, and no difference was seen between the different mixtures. The compounds are eliminated mainly in the urine, the acute oral toxicity is low and all mixtures showed irritating properties without a sensitizing potential. The olefin sulfonates were not mutagenic *in vitro* and no increased tumour rates were found in dermal and oral carcinogenicity studies.

Comparison of the three subgroups

The toxicological profile of the alkyl sulfates and the olefin sulfonates reveals many similarities. For all compounds the acute oral toxicity as well as repeated oral toxicity is relatively low. After multiple oral dosing, the gastrointestinal tract (dosing via gavage), and the liver were identified as target organs. The similarity between both subgroups is evident also for all other endpoints such as sensitization, mutagenicity, carcinogenicity and reproductive toxicity.
The database for the alkyl sulfonates is very limited. These substances are in between the two other groups, as they share the saturated alkyl chain with the alkyl sulfates and the sulfonic acid group with the α-olefin sulfonates. As for the alkyl sulfates and α-olefin sulfonates, the acute oral toxicity is low. If additional data for the sulfonates (see above) are taken into account, it can be assumed that the alkyl sulfonates also will cause skin and eye irritation, but no sensitizing or genotoxic effects. Longer-term studies as well as data concerning carcinogenicity or reproduction toxicity are missing. However, based on metabolism studies it can be concluded that the toxicokinetic properties of the alkyl sulfates and sulfonates are similar. In addition, the sulfonic acids are also distributed within the body only to the liver and kidneys. Therefore also an analogy of the target organs can be assumed (i.e., a possible difference in metabolites may not play a role in the toxicity of these compounds) and adverse effects for the so far missing endpoints are not to be expected.

In summary, the available toxicological data are supporting the common properties of the compounds of the whole category.
Below matrix gives an overview on the availability of data for the single category members:

[4] Greim H et al. (1994) Toxicity and ecotoxicity of sulfonic acids: structure-activity relationship. Chemosphere 28, 2203 - 2236

	IUCLID chapter											
CAS No.	**5.1.1**	**5.1.2**	**5.1.3**	**5.2.1**	**5.2.2**	**5.3**	**5.4**	**5.5**	**5.6**	**5.7**	**5.8.1**	**5.8.2**
Alkyl sulfates												
139-96-8	√	-	-	√	√	-	-	√	-	-	-	-
142-31-4	-	-	-	-	-	√	-	√	-	-	-	-
142-87-0	√	-	-	-	-	-	-	√	-	-	-	-
151-21-3	√	-	√	√	√	√	√	√	√	√	√	√
1072-15-7	-	-	-	-	-	-	-	-	-	-	-	-
1120-01-0	-	-	-	-	-	-	-	√	-	-	-	-
1120-04-3	-	-	-	-	-	-	-	-	-	-	-	-
1191-50-0	-	-	-	-	-	-	-	√	-	-	-	-
2235-54-3	√	-	-	√	√	√	-	-	-	-	-	-
3026-63-9	-	-	-	-	-	-	-	-	-	-	-	-
4706-78-9	-	-	-	-	-	-	-	-	-	-	-	-
7065-13-6	-	-	-	-	-	-	-	-	-	-	-	-
7739-63-1	-	-	-	-	-	-	-	-	-	-	-	-
13393-71-0	-	-	-	-	-	-	-	-	-	-	-	-
39943-70-9	-	-	-	-	-	-	-	-	-	-	-	-
68081-96-9	√	-	√	-	-	-	-	-	-	-	-	-
68081-97-0	-	-	-	-	-	-	-	-	-	-	-	-
68081-98-1	√	-	-	-	-	-	-	-	-	-	-	-
68585-47-7	√	-	-	-	-	-	-	-	-	-	-	-
68611-55-2	√	-	-	-	-	-	-	-	-	-	-	-
68890-70-0	√	-	-	√	√	√	√	√	√	√	-	√
68955-19-1	√	-	-	√	√	√	-	√	-	-	-	-
68955-20-4	√	-	-	√	√	√	√	√	√	-	-	√
73296-89-6	√	-	-	√	√	-	-	√	-	-	-	-
85586-07-8	√	-	-	√	√	√	-	√	-	-	-	√
85665-45-8	√	-	-	√	√	-	-	√	-	-	-	-
85681-68-1	√	-	-	-	-	-	-	-	-	-	-	-
86014-79-1	√	-	-	√	√	-	√	-	-	-	-	√
90583-10-1	√	-	-	√	√	-	-	√	-	-	-	-
90583-12-3	-	-	-	√	√	√	-	√	-	-	-	-
90583-13-4	-	-	-	-	-	-	-	√	-	-	-	-
90583-16-7	√	-	-	√	√	√	-	√	-	-	-	-
90583-18-9	√	-	-	√	√	√	√	√	√	-	-	-
90583-19-0	-	-	-	-	-	-	-	-	-	-	-	-
90583-23-6	√	-	-	√	√	√	-	√	-	-	-	-
90583-24-7	-	-	-	√	√	-	-	-	-	-	-	-
90583-27-0	-	-	-	√	-	-	-	√	-	-	-	-
90583-31-6	√	-	-	√	-	-	-	√	-	-	-	-
91648-54-3	-	-	-	-	-	-	-	-	-	-	-	-
91783-22-1	√	-	√	-	-	-	-	-	-	-	-	-
91783-23-2	-	-	-	-	-	-	-	-	-	-	-	-
96690-75-4	√	-	-	-	-	-	-	-	-	-	-	-
117875-77-1	-	-	-	-	-	-	-	-	-	-	-	-
Alkane sulfonates												
2386-53-0	-	-	-	-	-	-	-	-	-	-	-	-
5324-84-5	√	-	-	-	-	-	-	-	-	-	-	-
13419-61-9	-	-	-	-	-	-	-	-	-	-	-	-
13893-34-0	-	-	-	-	-	-	-	-	-	-	-	-
27175-91-3	-	-	-	-	-	-	-	-	-	-	-	-
68815-15-6	√	-	-	-	-	-	-	-	-	-	-	-
α-Olefin sulfonates												
11067-19-9	-	-	-	-	-	-	-	-	-	-	-	-
30965-85-6	-	-	-	-	-	-	-	-	-	-	-	-

	IUCLID chapter											
CAS No.	**5.1.1**	**5.1.2**	**5.1.3**	**5.2.1**	**5.2.2**	**5.3**	**5.4**	**5.5**	**5.6**	**5.7**	**5.8.1**	**5.8.2**
68439-57-6	√	-	√	√	√	√	√	√	-	√	-	√
85536-12-5	-	-	-	-	-	-	-	-	-	-	-	-
91082-14-3	√	-	-	-	-	-	-	-	-	-	-	-
91722-28-0	-	-	-	-	-	-	-	-	-	-	-	-
93686-14-7	√	-	-	-	√	√	√	√	-	-	-	-
863609-89-6	-	-	-	√	-	-	-	-	-	-	-	-
Different substances without CAS no.												
99999-99-9	√	-	√	√	√	√	-	-	-	-	√	√

Bold: HPV chemical; √: data available; -: no data available

2 GENERAL INFORMATION ON EXPOSURE

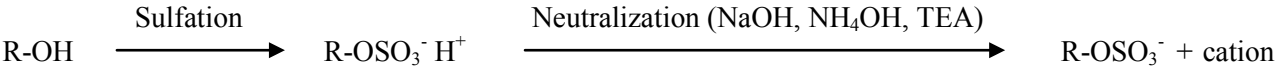
2.1 Production Volumes and Use Pattern

Production

Laundry and dishwashing surfactants are produced in Western Europe by 5 companies, in Northern America by 4 companies and in Japan by 3 companies (CEH, 2004).

Alkyl sulfates

Commercial alkyl sulfates are produced by sulfation of primary alcohols using sulfur trioxide or chlorosulfonic acid followed by neutralization with base (sodium hydroxide, ammonia, or alkanolamines such as triethanolamine) to produce the corresponding salt (HESA, 2003).



Alcohol **Alkyl sulfate**

where R is a linear, primary alkyl group.

The parent alcohols range in carbon chain length from C_8 to C_{18} and are predominantly linear. The linear-type alcohols include those derived from vegetable or animal sources via oleochemical processes and those synthesized by successive condensation of ethylene units via Ziegler chemistry. Such alcohols contain even carbon numbered alkyl chains only, and are produced in single carbon cuts or more usually wider cuts from C_6 through C_{22}.The essentially linear alcohols used to produce AS, also known as linear oxo-alcohols, are derived from linear higher olefins via oxo-chemistry. The feedstock linear olefins are typically derived from ethylene or normal paraffins. Such alcohols contain mixtures of even/odd or odd carbon numbered alkyl chains depending on the feedstock olefin, and are produced in grades ranging from C_7 through C_{15}. Typically > 40 - 80 % of the carbon chains are linear, the remainder being mono-branched 2-alkyl isomers, predominantly 2-methyl. The mono-branched isomers thus have a linear backbone. C_{12} through C_{15} grades are feedstocks for certain AS surfactants included in this dossier in support of the category assessment (HESA, 2003).

There is inherent variability in the alkyl chain length distribution of commercial surfactants derived from either oleochemical or petrochemical alkyl feedstocks, which stems from variations in the oleochemical feedstocks and/or the production processes. For example, linear AS designated as C_{10-16} or $C_{12/14}$ are derived from coconut-oil feedstock; linear AS designated as $C_{14/15}$ are derived from a petrochemical alcohol feedstock; linear AS designated as C_{12-18}, $C_{16/18}$ or $C_{14/18}$ are derived from either tallow or palm oil (HESA, 2003).

Alkane sulfonates

Of the large number of possible ways of synthesizing alkanesulfonates, only sulfochlorination (the reaction of alkanes with sulfur dioxide and chlorine to form alkane sulfonyl chlorides and their saponification with sodium hydroxide) and sulfoxidation (the reaction of alkanes with sulfur dioxide and oxygen and neutralization of the sulfonic acids) are of industrial importance. In sulfochlorination and sulfoxidation, mixtures of straight-chain alkanes with 12 to 18, preferably 13

to 17 carbon atoms, are used as starting materials. Both reactions proceed appropriate by a radical-chain mechanism. In sulfoxidation a sulfoperoxy acid first of all being formed (Ullmann, 2000).

Alkanesulfonates obtained from sulfochlorination processes are known as Mersolates. They are obtained in two steps:

$$RH + SO_2 + Cl_2 \rightarrow RSO_2Cl + HCl$$

$$RSO_2Cl + 2\ NaOH \rightarrow RSO_3Na + NaCl$$

The production process for sulfoxidation uses the following reactions:

$$RH + 2\ SO_2 + O_2 + H_2O \rightarrow RSO_3H + H_2SO_4$$

$$RSO_3H + NaOH \rightarrow RSO_3Na + H_2O$$

α-Olefin sulfonates

Commercial α-olefin sulfonates are produced by reaction of sulfur trioxide with linear α-olefins followed by neutralization and hydrolysis of sultone intermediates with sodium hydroxide. The product is a mixture of two components: mono-unsaturated alkene sulfonates and hydroxyalkane sulfonates, with the double bond and hydroxyl group located at various positions along the alkyl chain. The alkyl chain lengths of the α-olefins sulfonates generally range from C_{14} to C_{18} (HESA, 2003; Ullmann, 2000).

$$R\text{-}CH = CH_2 \xrightarrow{SO_3,\ \text{hydrolysis, neutralization}} CH_3\text{-}(CH_2)n\text{-}\underset{\displaystyle OH}{\underset{|}{CH}}\text{-}(CH_2)_2\text{-}SO_3^-\ Na^+$$

where R= alkyl chain; n =11 or 13

α- olefin → **hydroxyalkane sulfonate salt**

and

$$\xrightarrow{\qquad} CH_3\text{-}(CH_2)n\text{-}CH{=}CH\text{-}(CH_2)\text{-}CH_2\text{-}SO_3^-\ Na^+$$

n = 10 or 12

alkene sulfonate salt

AOS are derived from petrochemical C_8 or $C_{14\text{-}18}$ α-olefins produced by ethylene oligomerisation (HESA, 2003).

Production and Consumption Volumes

Alkyl sulfates

In 1993 ca. 33 000 tonnes/year alkyl sulfates were produced in Germany. Including imports and exports approx. 26 500 - 27 000 tonnes of alkyl sulfates were used (BUA, 1998). Estimated production volumes for single alkyl sulfates are listed in Table 2-1:

Table 2-1: Estimated production volumes of HPV substances in 1993 in Germany (BUA, 1998)

Chemical shorthand	**CAS No.**	**Production volume (t)**
C_{12-18} ASO_4 Na	68955-19-1	10 560
C_{16-18} ASO_4 Na	68955-20-4	9 240
C_{12} ASO_4 Na	151-21-3	4 950
C_{12-14} ASO_4 Na	85586-07-8	4 950
C_{12-16} ASO_4 Na	73296-89-6	2 640
C_{12-14} ASO_4 TEA	90583-18-9	660
C_{12} ASO_4 TEA	139-96-8	-*

* no production at all or produced only in very small scale (1993)

In a survey of producers by the CESIO Statistics Group, the total volume of alkyl sulfate surfactants used in Europe was estimated to be 102 000 tonnes in 1999 on an active matter basis. The tonnage of AS used in household detergents and cleaning products is estimated to be approx. 65 000 tonnes/year in Europe (HERA, 2002).

In addition the chain length distribution of the total tonnage including uses as household cleaning products plus other uses was determined by the CESIO survey (HERA, 2002). Of that 102 000 tonnes/a, the chain length distribution for 78 000 tonnes/a has been determined (Table 2-2):

Table 2-2: Chain length distribution of the European tonnage of alkyl sulfates via CESIO survey (HERA, 2002)

Chain length*	**Estimated Carbon distribution of alkyl sulfates (% weight)**	**Tonnage of alkyl sulfates (tonnes/year)**
C_{11} and below	1.4	1 179
C_{12}	29.3	23 109
C_{13}	10.6	8 364
C_{14}	25.6	20 445
C_{15}	6.0	4 722
C_{16}	11.7	9 204
C_{18}	13.2	10 404
C_{20} and above	1.9	1 462
Total		**78 888**

*) C_{17} is essentially absent from commercial alkyl sulfate surfactants

In 2003, the consumption in different World Regions was:

Table 2-3: Consumption of alkyl sulfates [tonnes/a] by World Region in 2003 (CEH, 2004)

World Region	Heavy-duty laundry powders	Heavy-duty laundry liquids	Light-duty powders and liquids	Other uses*	Sum
USA and Canada	92 000	-	-	26 000	118 000
Western Europe	43 000	22 000	5 000	35 000	105 000
Japan	3 000	1 500	-	7 000	11 500

*) includes personal care products and industrial, institutional and commercial uses

The production and use of alkylsulfates in Europe has declined dramatically during the last 5 years (Gamon, 2006). This is due to the increasing use of alternative surfactants which are not part of this category.

Alkane sulfonates

The use of alkane sulfonates in 1986 in Western Germany was estimated to 16 000 tonnes (Schoeberl et al., 1988). The production of secondary alkane sulfonates (= paraffin sulfonates) in Western Europe was estimated at 63 000 tonnes/a in 2003, the consumption at 60 000 tonnes/a (CEH, 2004).

α-Olefin sulfonates

In Western Germany less than 1 000 tonnes of C_{14-18} AOS were used in 1986 (Schoeberl et al., 1988).

In Western Europe, consumption was about 6 000 tonnes in 2003, in Japan, 3 000 tonnes were used in 2003. The amount consumed in the USA and in Canada in 2003 is not reported (CEH, 2004).

Use Pattern

Alkyl sulfates

Alkyl sulfates mainly have been used as wool-washing agents and as active ingredients in both light- and heavy-duty laundry formulations. They are also widely used in a variety of specialty products, including toothpastes, hair shampoos, antacids, cosmetics and in certain foods. Other uses are emulsion polymerization, froth flotation in pharmaceuticals, pigment dispersion, bubble baths, car shampoos, carpet cleansers, hand cleaning pastes, fire fighting foams, emulsifiers for insecticides and in printing ink manufacture (Roempp, 1995; Little, 1991; Painter, 1992).

According to CEH (2004) alkyl sulfates are used as household detergents, principally in shampoos and heavy-duty laundry powders and liquids.

α-Olefin sulfonates

In the United States α-olefin sulfonates (AOS) are used in laundry detergents, dishwashing products, household cleaning and personal care products. In the U.S., the main use in consumer products is in liquid hand soaps, with some use in shampoos (Little, 1993).

α-Olefin sulfonates are used in light-duty detergents, hand dishwashing, shampoos, bubble baths and synthetic soap bars. They are also used for cleaning upholstery and carpets. Industrial uses are reported for textile, leather and cosmetic industries (Roempp, 1995; Painter, 1992).

In the USA and in Canada almost all AOS was used in personal care products and industrial applications (amount not reported). In Western Europe, consumption was about 6 000 tonnes in 2003, the major use was in industrial and institutional cleaners with some small quantities used in light-duty liquids (specifically wool detergents) and personal care products. In Japan, 3 000 tonnes were used in 2003, the major use was in household detergents, and small volumes are currently used in personal care products (i.e. shampoo) (CEH, 2004).

2.2 Environmental Exposure and Fate

2.2.1 Sources of Environmental Exposure

The products of the ANS category are released down the drain during the intended use by the consumers. Sources of environmental exposure are domestic waste water and land application of sewage sludge. Human exposure occurs during use of personal care products. No data are available on releases to the environment during production.

There is a number of monitoring data available covering the products of the ANS category. In former investigations, alkyl sulfates, alkane sulfonates and α-olefin sulfonates were not monitored in surface waters as individual substances. Usually MBAS (Methylene blue active substance) was monitored, that includes all MBAS sensitive anionic surfactants. Therefore the ANS concentrations are overestimated by MBAS measurements. In more recent studies, substance-specific methods were developed which allow the determination of individual homologues.

Alkyl sulfates

The mean yearly concentration of two Japanese sewages was measured as MBAS (Oba et al., 1976) of which 1.4 and 1.3 mg/l was attributed to alkyl sulfates (AS) plus alkyl ether sulfates (AES). The biologically treated sewage effluents did not contain measurable amounts of AS and AES.

Concentrations of alkyl sulfates in U.K. in biologically treated sewage and river water were calculated to be 0.01 mg/l and 0.005 mg/l (worst case dilution 1:2), respectively (Gilbert and Pettigrew, 1984). The corresponding calculated concentration in sewage sludge was 800 mg/kg, in soil 0.02 mg/kg immediately after application of sewage sludge (50 m^3/ha).

In semiquantitative studies all homologues of AS from C_{10} to C_{19} were detected in sewage effluents and river waters (Painter, 1992). The sewage samples contained mainly C_{12} and C_{13} homologues. AS concentrations in sewage were less than a few hundred µg/l, in river waters only few µg or less.

In the influent of 2 trickling filter plants near Cincinnati, USA, alkyl sulfate concentrations in the inlet of the WWTPs varied daily in the range of <10 µg/l to 700 µg/l (24 hour mean 755 µg/l and 401 µg/l for two WWTPs), which is expected from consumer use of AS containing products. In the effluents the total AS concentrations were between 36.2 µg/l and 46.0 µg/l, the removal rates were determined to 90 % and 94 %, respectively. While in influent chain length was equally distributed between C_{12}, C_{14}, C_{15} with lesser amounts of C_{13}, C_{16}, C_{18}, treated effluent contained

predominantly C_{12}. This result is explained by preferential sorption. In the receiving surface water no alkyl sulfate homologues were found at a detection limit of 5 µg/l (Fendinger et al., 1992).

Popenoe et al. (1994) measured alkyl sulfates with a chain length from C_{12} to C_{15} in the effluent of a treatment plant receiving primarily domestic waste water. The concentrations of C_{13} and C_{15} ASO_4 were below 0.3 µg/l, while the C_{12} and C_{14} homologues could not be assessed due to an experimental artefact.

Anionic surfactants were monitored in the river Rur (Germany) October 1993 - December 1994 at two WWTPs at inlet, outlet, and surface waters. Alkyl sulfates were analysed by specific analytical method (Schroeder, 1995). The WWTP Monschau received predominantly domestic wastewater, WWTP Dueren received wastewater with a considerable amount of industrial wastewater. Concentrations of the sum of alkyl sulfates are listed below:

Table 2-4: Alkyl sulfate concentrations at WWTPs in the river Rur (Schroeder, 1995)

Origin of the sample	**Monschau (domestic wwtp, median values) (µg/l)**	**Origin of the sample**	**Dueren (domestic and industrial wwtp, mean values) (µg/l)**	**Dueren (median values) (µg/l)**
100 m upstream	1.4	100 m upstream	4	2
Inlet	140	Inlet	1028	380
Outlet	2	Outlet	7.4	4
1200 m below outlet	1	2800 m below outlet	10.2	2
2700 m below outlet	1	3800 m below outlet	8.4	3

In an effluent from a trickling filter plant in the USA, 4.6 µg/l (C_{12}), 1.2 µg/l (C_{13}), 3.9 µg/l (C_{14}) and 4.3 µg/l (C_{15}) alkyl sulfates were detected (McAvoy et al., 1998).

Matthijs et al. (1999) conducted a monitoring study in 7 biological treatment plants in the Netherlands. The detected concentrations of alkyl sulfates (C_{12}-C_{15}) in raw sewage were 700 µg/l (average value, range 130 - 1 290 µg/l), and in effluent 5.7 µg/l (1.2 - 12 µg/l). The total removal during sewage treatment was 99.2 % (99.0 - 99.6 %). Comparing predicted concentrations in raw sewage (calculated from national consumption) with measured values, the in-sewer removal was calculated to 55 % (range 18 - 85 %). A similar figure of 58 - 78 % was estimated by Fendinger et al. (1992).

Sanderson et al. (2006b) measured alkyl sulfates and alkyl ethoxysulfates by liquid chromatography-mass spectrometry in influent and effluent of 3 biological treatment plants in the USA. Additional measurements were conducted in the receiving surface waters and in sediment porewater. The concentrations attributed to C_{12}-C_{15} alkyl sulfates are:

Table 2-5: Alkyl sulfates concentrations measured in 3 treatment plants and the receiving surface waters in the USA and in porewater (Sanderson et al., 2006b)

Compartment	Water [µg/l]			Porewater [µg/l]		
Site	Lowell	Bryan	Wilmington	Lowell	Bryan	Wilmington
500 m above outlet	0.073	0.176	0.150	0.200	0.600	0.573
Influent	88	77.9	81.3	-	-	-
Effluent	2.59	0.269	0.199	-	-	-
2 m below outlet	0.167	0.121	0.065	1.385	0.895	0.725
50 m below outlet	0.087	0.107	0.010	0. 767	1.626	1.469
1000 m below outlet	0.087	0.112	0.038	1.431	0.671	1.725

Sanderson et al. (2006a) detected C_{12} and C_{14} alkyl sulfates in sediments from 3 locations in the USA corresponding to different expected exposure levels. The samples were taken from the top 2 - 5 cm of the sediment. The measured concentrations were in the range of 0.0125 - 0.021 mg/kg dw for C_{12} ASO_4 and 0.005 - 0.0035 mg/kg dw for C_{14} ASO_4, respectively.

Conclusions

The data matrix on analytical measurements of alkyl sulfates is rich and well documented. Alkyl sulfates were measured in raw sewages, effluents of waste water treatment plants, in receiving surface waters and their sediments. The data reveal that the substances are partially removed in the sewer system and nearly quantitatively removed in biological treatment plants. The concentrations in effluents of waste water treatment plants are mostly below 10 µg/l. In the receiving surface waters, in the 1980s and 1990s, most of the available values were below 5 µg/l, with a maximum of 10.2 µg/l. Sediment concentrations were between 0.0035 and 0.021 mg/kg dw indicating that accumulation in sediments is low.

Alkane sulfonates

Monitoring data for alkane sulfonates could not be identified.

α-Olefin sulfonates

The mean yearly concentration of two Japanese sewages was measured as MBAS, of which 0.164 mg/l and 0.160 mg/l were attributed to α-olefin sulfonates. The fractions of AOS were measured after removal of AS and AES, their fractions were estimated to be only 2.0 resp. 1.9 % of the total MBAS content. In treated effluents no AOS were found (Oba et al., 1976).

In 2004, α-olefin sulfonates were monitored at 7 locations of 4 rivers near two Japanese metropolitans. The rivers receive wastewater from both treatment plants and via direct discharges. In the river water, concentrations of C_{14}, C_{16} and C_{18}-AOS (alkenyl and hydroxyalkyl type) were measured by HPLC/MS. For C_{14}-AOS, the range was from below determination limit to 0.06 µg/l, with a median of 0.04 µg/l and a 95-percentile of 0.06 µg/l. For the sum of C_{14-18} AOS, the range was from below determination limit to 0.16 µg/l, with a median of 0.09 µg/l (Lion Co., 2005).

2.2.2 Photodegradation

Experimentally derived data about photodegradation are not available. EPI Suite v. 3.12 (2005) provides the possibility for calculating rate constants for atmospheric reactions with reactive species for indirect photodegradation. The half-lives for the reaction with hydroxyl radicals were calculated on the basis of the reaction constants estimated by EPI Suite and an OH-radical concentration of $5 \cdot 10^5$ molecules/cm^3. For alkyl sulfates, they are in the range of 17 - 42 hours (see Table 2-6). α-Olefin sulfonates may be susceptible to reaction with ozone. Half-lives from 1.4 - 2.1 h are estimated (ozone concentration $7 \cdot 10^{11}$ molecules/cm^3). Cis- and trans- alkene sulfonates may also react with nitrate radicals. Because of the lack of a chromophor direct photodegradation may not be relevant.

Since **alkyl sulfates**, **alkane sulfonates** and **α-olefin sulfonates** are not volatile (cf. 1.3 and 2.2.4), photodegradation in the atmosphere is expected to be not relevant.

Table 2-6: Estimated atmospheric half-lives of chemicals of the ANS category (EPI Suite v. 3.12, 2005)

CAS No.	Chemical Shorthand	Hydroxyl Radicals reaction: Half-Life at $5 \cdot 10^5$ OH/cm^3, 12-hr day	Ozone Reaction: Half-Life at $7 \cdot 10^{11}$ molecules/cm^3
Alkylsulfates, sodium salts			
142-31-4	**C_8 ASO_4**	**42 h**	
142-87-0	**C_{10} ASO_4**	**32 h**	
151-21-3	**C_{12} ASO_4**	**26 h**	
1191-50-0	C_{14} ASO_4	22 h	
1120-01-0	C_{16} ASO_4	19 h	
1120-04-3	C_{18} ASO_4	17 h	
Alkane sulfonates, sodium salts			
5324-84-5	**C_8 ASO_3**	**40 h**	
13893-34-0	C_{18} ASO_3	16 h	
α-Olefin sulfonates, sodium salts			
Not available	**C_{14} =ASO_3**	**4.9 - 5.4 h**	**1.4 - 2.1 h**
Not available	C_{16} =ASO_3	4.7 - 5.2 h	1.4 - 2.1 h
Not available	C_{18} =ASO_3	4.6 - 5.0 h	1.4 - 2.1 h

Bold: HPV chemical

2.2.3 Stability in Water

In hot alkaline and acidic media, alkyl sulfates hydrolyse to sulfate and the corresponding alcohol. Under environmental conditions **alkyl sulfates** should be stable in water (Kirk-Othmer, 2005). **Alkane sulfonates** as well as **α-olefin sulfonates** are stable to hydrolysis even at extreme pH values (Ullmann, 1987; Painter, 1992).

2.2.4 Transport between Environmental Compartments

Henry's law constants

Experimental data on Henry`s law constants are not available. Model calculations using EPI Suite v. 3.12 (2005) predict low to moderate volatility for linear **alkyl sulfates**, **alkane sulfonates**, and **α-olefin sulfonates** (cf. Annex II). However, the calculated data may not be a realistic reflection of the constants, since surfactant properties are not taken into account by the model. Due to the ionic nature of the substances, volatilization from the aqueous phase is not expected.

Sorption coefficients

Based on lipophilicity soil sorption coefficients (K_{OC}) characterize the distribution between soil organic matter and pore water. Since lipopilicity is a function of chain length estimated soil sorption coefficients rise with the number of carbons in the chain. The only experimental study for sorption of surfactants of this category was conducted with **alkyl sulfates**, sodium salts (homologues of chain lengths from 8 to 14) on sediment (organic carbon content 22 %) from an artificial pond (Marchesi et al., 1991). Sorption experiments were carried out at 25 °C and pH = 7.6 in 0.01 mol/l $NaHCO_3$. Sorption isotherms were determined already after 1 h contact time. Measured sorption coefficients on sediment are summarized in Table 2-7.

Table 2-7

: Experimentally derived sediment-water partition coefficients K_d (l/kg) and sorption coefficients (K_{OC}) for alkyl sulfates on sediment (Marchesi et al., 1991)

CAS No.	Chemical Shorthand	K_d	K_{OC} (exp)	Sorption potential according to Blume (1990)
142-31-4	**C_8 ASO_4 Na**	**16.7 - 22.3**	**75 - 101**	**low**
1072-15-7	C_9 ASO_4 Na	26.1 - 32.6	118 - 147	low
142-87-0	**C_{10} ASO_4 Na**	**27.1 - 39.5**	**122 - 178**	**low-moderate**
Not available	C_{11} ASO_4 Na	76.7 - 81.7	346 - 368	moderate
151-21-3	**C_{12} ASO_4 Na**	**70.2 - 99.1**	**316 - 446**	**moderate**
3026-63-9	C_{13} ASO_4 Na	135.0 - 142.7-	608 - 642-	strong
1191-50-0	C_{14} ASO_4 Na	296.7 - 347.9	1337 - 1567	strong-very strong

Bold: HPV chemical

From this study, **alkyl sulfate** homologues C_8 - C_9 exhibit low sorption potential to sediments, C_{10} low to moderate, C_{11} - C_{12} homologues moderate sorption, while C_{13} - C_{14} homologues exhibit strong to very strong sorption potential to sediments. This is consistent with the hypothesis, that sorption increases with the number of carbons and lipophilicity. Weak hydrophobic interaction was found to be the sorption mechanism. For sodium dodecyl sulfate sorption followed a two phase shape, a first rapid sorption in the first 20 min, followed by a slow sorption phase up to 9 hours. The equilibration time of one hour, however, in the experiments is very short for sorption experiments. Kaolinite and peroxide treated sediment showed negligible sorption. Some contribution of primary degradation (biodegradation) to the second sorption phase was assumed by Marchesi et al. (1991).

The role of organic matter in sediments on the adsorption of $C_{12}ASO_4$ Na was studied by Marshall, House, and White (2000). With a natural pond sediment adsorption isotherms were linear, a K_d value of 30.78 l/kg was determined. Removal of the natural organic matter content reduced markedly the adsorption capacity of the sediment. The authors concluded that the adsorption occurs mainly via hydrophobic interactions.

Model calculations for **alkyl sulfates** predict preferentially strong to very strong tendency for partition into soil organic matter. Comparing EPI Suite calculations of soil sorption and experimental derived K_{OC} the calculated values are significantly higher (more than 1 order of magnitude). For example C_8ASO_4 Na (K_{OC} (exp) 75 - 101 versus K_{OC} (calc) 883), $C_{10}ASO_4$ Na (K_{OC} (exp) 122 - 178 versus K_{OC} (calc) 3 004), C_{12} ASO_4 Na (K_{OC} (exp) 316 - 446 versus K_{OC} (calc) 10 220), and C_{14} ASO_4 Na (K_{OC} (exp) 1567 - 1337 versus K_{OC} (calc) 34 - 770).

However, one should keep in mind that surfactancy (the fact that surfactants tend to stay in the boundary layer between the phases) and dissociation is not taken into account in the EPI Suite estimations. Therefore calculated K_{OC} values should not be used for the exposure assessment.

Urano (1984) studied the adsorption of C_{12}-**AOS** in several sediments collected in Japanese rivers. The experiments were carried out at 25 °C and pH 7.0 ± 0.5. The adsorption isotherms were found to be nearly equal for the various sediments, except one sediment. Adsorption was determined by the content of organic substances. For C_{12}-**AOS** the K_{OC} was 0.65 and n = 1.1. The result demonstrates that the sorption potential of **α-olefin sulfonates** is significantly below that of alkyl sulfates. Adsorption of 2-**Hydroxy alkanesulfonates** is expected to be even lower due to the presence of the hydroxyl group (calculated values are 73 for C_{14}, 250 for C_{16}, and 849 for C_{18}).

There are no experimentally derived soil sorption coefficients available for **alkane sulfonates**. Assuming the same sorption mechanism as alkyl sulfates and assuming overestimation of the soil sorption by EPIWIN calculations, K_{OC} of **alkane sulfonate** C_8 ASO_3 Na (K_{OC} (calc): 38) should be negligible.

Summary of distribution in the environment

The results underline that the target compartment for **alkyl sulfates**, **alkane sulfonates**, and **α-olefin sulfonates** is the hydrosphere. When released into surface waters, relevant fractions of the alkyl sulfates with higher chain length are expected to adsorb onto sediments. When sewage sludge is used as fertilizer, the compounds can reach agricultural soils. However, due to the ready biodegradability, accumulation in soils or sediments is not expected. Modelling environmental partitioning based on fugacity models (e.g. Mackay level I-III) does not seem to be appropriate for surfactants.

2.2.5 Biodegradation

Aerobic biodegradation

Alkyl sulfates

The ability of micro-organisms to mineralize alkyl sulfates is ubiquitous in nature and most likely evolved in response to the abundance of natural sulfates.

For linear alkyl sulfates which contain 6 or more carbons the process starts with enzymatic hydrolysis of the ester bond, producing the corresponding alcohol and inorganic sulfate salt. The alcohol is enzymatically oxidised to aldehyde and carboxylic acid, which is further metabolized by β-oxidation (Gilbert and Pettigrew, 1984).

There are numerous studies for members of the ANS category. They are listed in Annex III Table III-1. In the following, only a selection of results is discussed to illustrate specific aspects, like dependency on alkyl chain length, primary degradation vs. mineralization, influence of counterion or simulation tests.

Chain length dependency

The matrix of data includes totally 12 Closed Bottle Tests (OECD 301 D) conducted with the sodium salts of alkyl sulfates. In all tests the criteria for ready biodegradability were fulfilled. There is a general tendency of the oxygen uptake to decrease slowly as the alkyl chain length increases, but even with C_{18} ASO_4 Na the pass level for ready degrabability was reached within 14 days. Results of Closed Bottle Tests with single chain homologues are presented in Table 2-8:

Table 2-8

: Biodegradation of alkyl sulfates, sodium salts in the Closed Bottle Test (OECD 301 D)

CAS No.	Test substance	O_2 uptake	10 / 14 d window	Reference
142-31-4	**C_8 ASO_4 Na**	**91 % in 30 d**	**10 d window fulfilled**	**Cognis (2001h)**
142-87-0	**C_{10} ASO_4 Na**	**98 % in 30 d**	**14 d window fulfilled**	**Cognis (2001i)**
151-21-3	**C_{12} ASO_4 Na**	**94 / 97 % in 28 d** **ca. 85 % in 30 d**	**10 d window fulfilled**	**Henkel KGaA (1996b)** **Fischer and Gerike (1975)**
1120-01-0	C_{16} ASO_4 Na	69 % in 30 d	10 d window fulfilled	Cognis (2001j)
1120-04-3	C_{18} ASO_4 Na	70 % in 30 d	10 d window fulfilled	Cognis (2001k)

Bold: HPV chemical

In the OECD 301 E Test, alkyl sulfates with a chain length between 8 and 14 degraded to 90 - 100 % after 8 days (Sanchez-Leal, 1991).

Primary degradation and mineralization:

The relation between primary degradation and mineralization was demonstrated in different Manometric Respirometry Tests (OECD 301 F) and modified Sturm Tests (84/449/EEC) using activated sludge as inoculums (Shell, 1992a) (see Table 2-9).

Table 2-9: Biodegradation rates (after 28 days) of alkyl sulfates, sodium salts in OECD 301 F and 84/449/EEC tests (Shell, 1992a)

CAS No.	Test substance	OECD 301 F			84/449/EEC		
		O_2 uptake	DOC	MBAS	$ThCO_2$	DOC	MBAS
91783-23-2	C_{12-13} ASO_4 Na	74 - 83 %	87 - 93 %	100 %	79 - 82 %	88 - 91 %	99 %
68890-70-0	**C_{12-15} ASO_4 Na**	**80 - 81 %**	**57 - 60 %**	**99 %**	**75 - 97 %**	**88 - 95 %**	**99 %**
91648-54-3	C_{14-15} ASO_4 Na	77 - 96 %	71 %	100 %	58 - 76 %	83 - 90 %	99 %

Bold: HPV chemical

All 3 test substances were mineralized to a large extend. The MBAS removal of 99 - 100 % indicates that the sulfate unit and therefore the surfactancy properties of the substrates were quantitatively removed.

Effect of counterion:

The data matrix includes a number of biodegradation tests conducted with with different counter ions. An overview is presented in Table 2-10:

Table 2-10

: Biodegradation of alkyl sulfates with different counter ions

Chain length	CAS No.	Cation	Guideline	Result	Reference
C_{12-14}	**85586-07-8**	**Na**	**OECD 301 D**	**96 - 102 % (28 d)**	**Henkel KGaA (1996a)**
	90583-23-6	Mg	OECD 301 E	93 - 99 % (28 d)	Henkel KGaA (1992a)
	90583-16-7	MEA	OECD 301 D	71 - 90 % (28 d)	Henkel KGaA (1992f)
	90583-18-9	**TEA**	**OECD 301 E**	**97 - 98 % (28 d)**	**Henkel KGaA (1999a)**
C_{12-18}	**68955-19-1**	**Na**	**OECD 301 D**	**74 - 100 % (30 d)**	**Cognis (2004)**
	90583-13-4	NH_4	OECD 301 E	91 - 94 % (28 d)	Henkel KGaA (1992b)
C_{8-14}	85665-45-8	TEA	OECD 301 D	92 - 97 % (30 d)	Cognis (2003a)
	90583-10-1	NH_4	OECD 301 E	96 % (28 d)	Henkel KGaA (1991a)

Bold: HPV chemical

The results demonstrate that alkyl sulfates with MEA, TEA or Mg as cations are readily biodegradable, as well as the sodium salts. From these results an influence of the nature of the counter-ion onto degradation cannot be derived.

Simulation tests

Removal of alkyl sulfates in biological treatment plants was simulated in several tests. In a Modified S.C.A.S. Test according to the OECD Guideline 302 A, a DOC removal of 95 ± 3 % for C_{12-13} ASO_4 Na and 97 ± 3 % for $C_{12-18}ASO_4Na$ was observed (Procter and Gamble, 1991b, 1991c). In an EEC Activated Sludge Simulation Test with $C_{12-13}ASO_4Na$, the observed removal rates were 94.5 % DOC and 99.7 % MBAS, $C_{14-15}ASO_4Na$ degraded to 92.7 % DOC and 100 % MBAS (Shell, 1992b). In a Coupled Units Test similar to OECD 303A $C_{16-18}ASO_4Na$ shows 96 ± 2 % DOC removal and 92 ± 4 % TOC removal (Cognis, 2001l). In two Coupled Units Tests with $C_{12}ASO_4Na$ as test substance, DOC removal of 96 - 107 % (Fischer and Gerike, 1975) and 107 % (Gerike and Fischer, 1979) were observed.

The complete biodegradability of $C_{12-14}ASO_4Na$ was demonstrated in a metabolite test according to Gerike (Procter and Gamble, 1992a). The test substance degraded to 100 %, this result ensures that no recalcitrant metabolites are formed.

Rapid degradation of C_{14} ASO_4 Na in activated sludge from sewage treatment plants was demonstrated in a die-away test (Procter and Gamble, 1996b). The total degradation (CO_2 evolution + inclusion into biomass) was 54 % after 15 min, 63 % after 1 hand 77 % after 24 h. Primary degradation was very rapid, with less than 5 % remaining after 15 min.

Further studies are available which reflect the degradation of alkylsulfates closer to surface water conditions. In river water which was collected downstream and upstream of a sewage treatment plant, the reaction rate was determined by measurements of the CO_2 evolution from 14-C labelled $C_{12}ASO_4Na$. The mineralization kinetics was found to be of first order with half-lives in river water of 0.9 d in upstream and 1.0 d in downstream water. When the river water was additionally spiked with sediment, the half-lives were determined to be 1.0 d in upstream and 0.6 d in downstream water (Procter and Gamble, 1993a).

In cultures of *Pseudomonas* C12B, biodegradation of C_{12} ASO_4 Na was found to be accelerated in the presence of natural sediments, compared to sediment-free cultures. This effect was explained by simultaneous attachment of both the alkyl sulfate and bacteria to the sediment (Marchesi et al., 1997; Marshall, House, and White, 2000).

Vives-Rego et al. (1987) spiked natural seawater with 20 mg/l $C_{12}ASO_4Na$ and found removal rates, based on MBAS measurements, between 0.26 and 0.34 d.

Alkane sulfonates

Linear alkane sulfonates biodegrade via a keto-bisulfite intermediate, which is further hydrolysed into bisulfite (HSO_3^-) and the corresponding aldehyde, which is then oxidised to the carboxylic acid. Bisulfite is chemically oxidised to sulfate in the environment. From this point onwards the biodegradation pathway is the same as for the alkyl sulfates (Painter, 1992).

Sanchez Leal et al. (1991) tested alkane sulfonates with a carbon chain length in the range between C_8 and C_{14} in a Modified OECD Screening Test (OECD 301 E). All test substances degraded to 90 - 95 % within the test period of 14 - 16 d. Based on this test alkane sulfonates can be classified as readily biodegradable.

The HPV substance C_8 ASO_3 Na was tested in the Modified Sturm Test according to OECD 301 B

(inoculum: activated sludge, 53 - 56 % $ThCO_2$ and 88 - 87 % DOC in 35 d) and can be classified as readily biodegradable (Stepan Co., 1994). The homologue $C_{18}ASO_3Na$ was shown to be readily biodegradable in the Closed Bottle Test according to OECD 301 D to 81 % BOD/COD removal in 30 d. Garden mould was used as inoculum (Cognis, 2001p).

α-Olefin sulfonates

The biodegradation pathway for α-olefin sulfonates remains largely unknown, however given the biochemistry involved it is speculated that the pathway probably involves formation of bisulfite (HSO_3^-) and an unsaturated aldehyde, similar to the way in which alkyl sulfonates biodegrade. Chemical oxidation of the former and enzymatic oxidation of the latter would then result in inorganic sulfate and a saturated carboxylic acid. From this point onwards the biodegradation pathway would be the same as for the alkyl sulfates (Painter, 1992).

α-Olefin sulfonates were tested according OECD 301 B, 301 C, and 301 D. In all tests the substances fulfilled the criteria of ready biodegradability (see Table 2-11).

Table 2-11

: Biodegradation of α-olefin sulfonates

Guideline	Test substance	CAS No.	Inoculum	Result	Reference
301 D	C_{12}=/$OHASO_3Na$	30965-85-6	Garden mould suspension	100 % BOD/COD in 30 d	Cognis (2001n)
301 C	C_{12}=/$OHASO_3Na$	30965-85-6		62 - 100 % BOD/TOD in 14 d	Urano and Saito (1985)
301 C	**C_{14}=/$OHASO_3Na$**	**93686-14-7**	**Activated sludge**	**BOD = 61 - 74 % in 28 d TOC = 79 - 89 %**	**MITI (1995)**
301 D	C_{16}=/$OHASO_3Na$	11067-19-9	Garden mould suspension	82 % ThOD in 30 d	Cognis (2001o)
301 B	**C_{14-16}=/$OHASO_3$ Na**	**68439-57-6**	**Activated sludge**	**70 - 90 % $ThCO_2$ in 28 d 93 - 99 % DOC in 28 d**	**Stepan Co. (1992)**
301 D	**C_{14-16}=/$OHASO_3$ Na**	**68439-57-6**	**Activated sludge**	**78 % of ThOD in 28 d**	**Kao Co. (1991)**
301 C	**C_{14-18}=/$OHASO_3$ Na**	**863609-89-6**	**Activated sludge**	**BOD = 98 % in 15 d TOC = 98 % MBAS = 100 %**	**Miura et al. (1979)**
301 D	C_{15-18}=/$OHASO_3$ Na	91082-14-3	Garden mould suspension	82 % BOD/COD in 30 d	Cognis (2001q)

Bold: HPV chemical

The influence of the alkyl chain length on biodegradation was studied using a modified shake flask procedure with CO_2 evolution and MBAS measurements as test parameters and an inoculum acclimatized to the test compounds (Kravetz, Chung, and Rapean, 1982). For comparison, commercial samples of a modified Ziegler-based AOS were included. CO_2 evolution decreased

slightly in amount and rate as AOS carbon chain length increased in the C_{12} to C_{18} range. C_{12} and C_{14} AOS degraded similarly to approx. 60 %, while C_{16} and C_{18} AOS reached ca. 55 % CO_2 evolution after 16 d incubation. Primary degradation measured by MBAS indicated for all substances at least 95 % disappearance after 4 days. Degradation of the AOS blends was comparable to their corresponding monocarbon cuts.

Anaerobic biodegradation

An important difference between sulfates and sulfonate-type surfactants, is their anaerobic biodegradation profile. **Alkyl sulfates** are known to biodegrade rapidly and completely under anoxic conditions, to CO_2, CH_4 and H_2S (Painter, 1992).

SDS ($C_{12}ASO_4Na$) is degradable under anaerobic conditions with digester sludge (ca. 91 % after 28 days, SIDS Report Sodium Dodecylsulfate) and $C_{12\text{-}16}ASO_4Na$ is readily biodegradable under anaerobic conditions as well (89.8 % after 35 days, Cognis, 2003b). After 15 days of incubation, Nuck and Federle (1996) measured a gas production ($CH_4 + CO_2$) of 80 % of the theoretical value in an anaerobic die-away test with $C_{14}ASO_4Na$ as test substance. In an ECETOC test on anaerobic degradation, the technical product $C_{14\text{-}18}ASO_4Na + C_{18}=ASO_4Na$ was degraded by 96.6 % after 71 d (Henkel KGaA, 1992c). Salanitro and Diaz (1995) observed after 40 - 50 days MBAS removal of 99 % with $C_{12\text{-}14}$ ASO_4 Na and 96 - 99 % with $C_{14\text{-}15}$ SO_4Na as test substance. Based on gas production, anaerobic degradation rates of 37 - 80 % ($C_{12\text{-}13}ASO_4Na$), 41 - 59 % ($C_{12\text{-}15}ASO_4Na$), and 40 - 82 % ($C_{14\text{-}15}ASO_4Na$) were observed (Shell 1992a).

For the **primary alkane sulfonates**, the weight of evidence suggests that these compounds do not biodegrade anaerobically, due to the recalcitrance of the C-S bond under anoxic conditions (Painter, 1992).

For **α-olefin sulfonates** contradictory results are reported. Itoh, Naito, and Unemoto (1987) tested a number of surfactants and found that AOS was the least degraded anaerobically. In contrast to this result, Oba, Yoshida, and Tomiyama (1967) found 31 % degradation of $C_{15\text{-}18}$ AOS when anaerobic sludge was used as inoculum, while with anaerobic sludge from a septic tank 43 % degradation after 28 d were obtained.

Summary of biodegradation

The rapid aerobic biodegradation of linear **alkyl sulfates** and **alkane (olefin) sulfonates**, as well as their high level of removal in sewage treatment, has been extensively documented in the literature. Excellent reviews about biodegradation of linear alkyl sulfates and alkane (olefin) sulfonates are available (Little, 1991, 1993; Painter, 1992).

The substances of the category are readily biodegradable. Mineralization of alkyl sulfates decreases slightly as chain length increases, but the higher homologues are still regarded as readily biodegradable. Poor degradation results obtained in some tests do not disprove this judgement, as in other tests for all components ready degradability was demonstrated. Biodegradation of **alkylsulfates** is independent from the counter-ion.

The first step of biodegradation of **alkyl sulfates** is the enzymatic hydrolysis of the ester bond producing the corresponding alcohol, while **alkane sulfonates** form the corresponding aldehyde via keto-bisulfite. Biodegradation pathway of **α-olefin sulfonates** is proposed similar to that of alkane sulfonates, forming bisulfite and unsaturated aldehyde. Alcohols and aldehydes are oxidised to carboxylic acids which are ultimately biodegraded by β-oxidation. Biodegradation is accompanied with early loss of surfactant properties and therefore by loss of toxicity. Consequently

primary degradation (measured as MBAS removal) should be regarded as the critical parameter for the assessment, instead of mineralization (O_2, CO_2 or DOC removal). All substances of the ANS category fulfil the criterion of ready biodegradability based on mineralization (including the 10 d window).

The rapid degradation in surface water was demonstrated in a mineralization study, in which half-lives around 1 day were determined in river water. Primary degradation is expected to be more rapid. Monitoring data from studies in the P&G experimental stream facility (cf. section 4.1) show that there is significant biodegradation of test substances even in a short section of experimental stream with river water.

In seawater, degradation half-lives between 0.26 and 0.24 d were found.

Sulfates and sulfonate-type surfactants differ in their anaerobic biodegradation profile. Alkyl sulfates biodegrade rapidly and completely under anoxic conditions, to CO_2, CH_4, and H_2S. For the sulfonated surfactants, the weight of evidence suggests that these do not biodegrade anaerobically, due to the recalcitrance of the C-S bond under anoxic conditions. Reports of partial degradation by some investigators may be due to the fact that conditions were not entirely anoxic, initially.

Removal in waste water

Studies simulating the actual situation in sewage treatment plants more closely, like activated sludge simulation tests and coupled units tests have been performed with several **alkyl sulfates**. They all yield degradation rates (mineralization rates) in excess of 90 % (sodium dodecyl sulfate: Fischer and Gerike 1975, Gerike and Fischer, 1979; $C_{16\text{-}18}$ alkyl sulfate, sodium salt: Cognis, 2001). The efficient removal is further demonstrated by monitoring data from WWTPs showing 99 % elimination rates of 18 - 85 % in the sewer and overall 99 % in the sewer and the sewage treatment plant.

2.2.6 Bioaccumulation

Bioaccumulation studies are available for the C_{12}, C_{14}, and C_{16} homologues of **alkyl sulfates**, sodium salts.

Several studies to determine bioconcentration factors have been conducted for $C_{12}ASO_4Na$. Bioconcentration factors (BCF) were 2.1 - 5.3 for *Cyprinus carpio* (fish, fresh water, Wakabayashi et al., 1978, 1980, 1981), and ca. 1.5 for *Carassius auratus* (fish, fresh water, Tovell, Howes, and Newsome, 1975). Different exposure concentrations had no effect on the degree of bioconcentration. Bioaccumulation of C_{12} ASO_4 Na is therefore considered to be low.

The total body burden of fish (carp) exposed to ^{35}S-labeled alkyl sulfates, sodium salts (C_{12} ASO_4 Na, C_{14} ASO_4 Na, and C_{16} ASO_4 Na) in water reached equilibrium within 24 - 72 hours. Alkyl sulfates were absorbed first mainly through the gills, then distributed to internal organs by blood and finally concentrated in the gall bladder. When transferred to clean water, 50 % of the radioactivity was eliminated within 3 days. Total body burden reaches higher levels for the longer chain length surfactants (Wakabayashi et al., 1980, see Table 2-12).

Table 2-12

: Bioconcentration factors of alkyl sulfates in fish

CAS No.	Chain length	Species	BCF	Clearance time (ct_{50}) [hours]	Reference
151-21-3	**C_{12}**	***Carassius auratus***	**ca. 1.5**	**decrease after 24 h: 38 (in unfed fish) / 68 % (in fed fish)**	**Tovell, Howes, and Newsome (1975)**
151-21-3	**C_{12}**	***Cyprinus carpio***	**ca. 4**	**ca. 72**	**Wakabayashi et al. (1978)**
151-21-3	**C_{12}**	***Cyprinus carpio***	**3.9 - 5.3**	**-**	**Wakabayashi et al. (1981)**
151-21-3	**C_{12}**	***Cyprinus carpio***	**2.1**	**ca. 100**	**Wakabayashi et al. (1980)**
1191-50-0	C_{14}	*Cyprinus carpio*	11	ca. 60	Wakabayashi et al. (1980)
1120-01-0	C_{16}	*Cyprinus carpio*	73	not determined (ca. 50 % after 72 h, up to 120 h no further decrease)	Wakabayashi et al. (1980)

Bold: HPV chemical

Bioconcentration factors for the three linear alkyl sulfates (C_{12} to C_{16}) are <100, even for $C_{16}ASO_4Na$, which has a calculated log K_{OW} =3.65 (Table II-1 Annex II). Both BCF and depuration time (the latter at least for 12 and 14 carbons in the alkyl chain), indicate that the substances are not bioaccumulative up to 16 carbons in the alkyl chain. For higher chain length (C_{18}) no experimental data on bioaccumulation are available.

For **alkane sulfonates** and **α-olefin sulfonates** no experimental data are available.

Conclusion

It can be concluded from the experimental data that the bioaccumulation potential of **alkylsulfates** at chain lengths up to C_{16} is low. The chemistry and physical properties of **alkane sulfonates** and **α-olefin sulfonates** are similar to AS. Hence, bioconcentration factors for AOS and alkane sulfonates are expected to be similar to those of the AS.

2.3 Human Exposure

2.3.1 Occupational Exposure

The chemicals of this category are manufactured for use in consumer and commercial/institutional product formulation and are not used as intermediates/derivatives for further chemical manufacturing processes.

Potential occupational exposures include the manufacturing and/or professional use of alkyl sulfate containing products, such as detergents, personal care products, paints, emulsifiers, wetting agents

in the food and feed industries, adhesives, cellophane, paper and paperboard, coatings, closures, rubber articles and textiles.

The alkane sulfonates are used in surfactant mixtures for shampoos and in liquid dishwashing detergents (e.g. washing-up liquids) often in conjunction with alkyl ether sulfates (AES) and in concentrated shampoos, in textile and leather auxiliaries (mercerising), preparations for cleaning metal, steam jets and pickling baths.
In the USA almost all alpha olefin sulfonate was used in personal care products and industrial applications (amount not reported). In Western Europe, the major use was in industrial and institutional cleaners with some small quantities used in light-duty liquids (specifically wool detergents) and personal care products. In Japan, the major use was in household detergents, and small volumes are currently used in personal care products (i.e. shampoo) (CEH, 2004).

Exposure during Manufacturing

During manufacturing and formulating, workers may potentially be exposed by the dermal and respiratory routes. In a survey among companies producing and processing the chemicals of this category, the personal protective equipment worn by workers and the engineering controls in place was investigated. Dermal exposure is the most likely route of exposure for the handling of aqueous solutions and is mitigated by protective clothing, eyewear, and gloves. For substances in the powdered or granulated state where inhalation of dust is the prevailing route of exposure, engineering controls (e.g., closed system operation, exhaust ventilation, dust collection) are in place to mitigate exposure. In the EU, Japan and the USA, there are no exposure limits for alkyl sulfates or -sulfonates. However, dust exposure should be limited to 2 mg/m^3, the limit concentration foreseen for caustic soda (NaOH) and potash (KOH). In the Sponsor country, dust measurements at the most critical site in the manufacturing process (filling of powdered and granulated products) yielded concentrations between 0.2 and 1.3 mg/m^3 for alkyl sulfates (Cognis, 2007).

Based on the industrial hygiene assessment, for tasks where a short-term exposure greater than 2 mg/m^3 cannot be excluded, workers are instructed to wear a portable respiratory device in addition to standard protective equipment (overalls, goggles, and gloves).

Exposure of Downstream Users

Professional downstream users may be exposed to liquid and/or aerosol or dust. Since the primary hazard of the category chemicals is skin and eye irritation, the usual precautions must be observed in handling to prevent contact with clothes, skin and in particular with the eyes. Workers are recommended to wear protective equipment (safety gloves and glasses and protective clothes). Information is provided to the professional users through the safety data sheets.

2.3.2 Consumer Exposure

The chemicals of this category are used in consumer cleaning and personal care products, usually in conjunction with other surfactants.

The alkyl sulfates are used in household cleaning products (laundry and liquid dishwashing detergents, dispersing agents, hard surface cleaners), in personal care products (shampoos, hair conditioners, liquid soaps, shower gels, toothpaste), and in additives for plastics and paints. Minor uses are the following applications in food: emulsifier, whipping agent, surfactant in fruit drinks,

wetting agent in crude vegetable oils and animal fats, or a use in adhesives, cellophane, paper and paperboard, coatings, closures, rubber articles and textiles.

The alkyl sulfates C_{8-14} ASO_4 Na, C_{8-14} ASO_4 NH_4, C_{14-18} ASO_4 and $C_{14-18/=18}$ ASO_4 Na are not used for consumer products (Cognis, 2007a). Typically, alkyl sulfates are applied in consumer products at concentrations between 3 and 5%. A survey performed in the frame of the HERA project (Human and Environmental Risk Assessments on ingredients of household cleaning products) of alkylsulfate concentrations in European consumer household cleaning products resulted in maximum concentrations between 0.1 and 20% (HERA, 2002) which is also representative for the Sponsor country. Maximum concentrations in personal care products in the sponsor country range from 2% to 14% (IKW, 2007). Usually, alkyl sulfates are used in conjunction with other surfactants that attenuate the irritant properties sufficiently to avoid consumer problems. The mixed surfactant systems form micelles that typically lead to a reduction in irritation potential of the mixture, compared to the irritation potential of the individual ingredients (Dillarstone & Paye, 1993, Effendy & Maibach, 2006; Paye et al, 2006). Furthermore, where skin contact occurs, application conditions like use in rinse-off products only, high dilution during application, short contact time, use in solid form or tablets sealed by individual package make sure that the inherent irritation potential of alkyl sulfates is sufficiently controlled. This is demonstrated by the long history of safe use of alkylsulfates in household cleaners and personal care products. A risk assessment taking into account all possible routes of consumer exposure through the use of alkylsulfates in detergents and cleaners has been performed under the HERA project (HERA, 2002). The cumulative systemic exposure through oral, dermal and inhalative contact was estimated to be 5.93 µg/kg bw/day, which is several orders of magnitude lower than the determined NOELs.

The alkane sulfonates are used in surfactant mixtures for shampoos and foam bath products (Biermann, 1987), and in liquid detergents (e.g. washing-up liquids) often in conjunction with alkyl ether sulfates (AES) and in concentrated shampoos, in textile and leather auxiliaries (mercerising), preparations for cleaning metal, steam jets and pickling baths (Painter, 1992).

In Western Europe, the major use of α-olefin sulfonates is in industrial and institutional cleaners with some small quantities used in light-duty liquids (specifically wool detergents) and personal care products. In Japan, the major use is in household detergents, and small volumes are currently used in personal care products (i.e. shampoo) (CEH, 2004).

Potential exposure to surfactants of this category includes dermal contact; there is the potential for eye contact during handling and use. Skin and inhalation exposure to aerosol mists may also occur through the use of spray cleaners. Short-term exposure to dust may occur by the use of products in powder form only, other application forms, like tablets or liquids being of no concern for the inhalation route. Generally, the average particle size in powder detergents is far in excess of respirability, since the surfactants in powder form used in consumer products are sieved to retain only non-respirable particles. In addition consumer detergents are specifically formulated to form non-dusting powders or are provided in the form of tablets sealed by individual package allowing only limited short-term exposure.

Chemicals in this category are used in consumer cleaning and personal care products, which may be used as is, or diluted prior to or during use. Dermal contact is expected with these products. There is some potential for incidental or accidental ingestion of, inhalation of, and/or eye contact with products during handling and use. Exposure to chemicals in this category in formulated consumer products is mitigated by following use and precaution instructions on product labels. Product labels reflect the hazard potential of the chemical ingredients in the product. These product labels also include first aid instructions to accompany each hazard warning. For example, products

may include eye and skin irritancy warnings along with instructions to rinse thoroughly if dermal or other exposure occurs.

3 HUMAN HEALTH HAZARDS

3.1 Effects on Human Health

3.1.1 Toxicokinetics, Metabolism and Distribution

There are several studies available on individual compounds, i.e. components of the mixtures which are subject of this report. This includes different chain lengths and counter ions. Table 3-1 gives an overview of the available data.

Absorption

Oral

Alkyl sulfates

After oral administration, alkyl sulfates are well absorbed in rats, dogs and humans (Denner et al., 1969; Burke et al., 1975; Merits, 1975; Black & Howes, 1980). This was indicated by excretion of up to 98 % of the dose administered (maximum for C_{12}) in the urine and by comparison of excretion after oral and i.v. or i.p. application for C_{11} (Burke et al., 1976), C_{12} (Denner et al., 1969) and C_{18} (Burke et al., 1975) alkyl sulfates.

Alkane sulfonates

Alkane sulfonates are well absorbed in the gastrointestinal tract in rats. Absorption of the alkane sulfonates may decrease with increasing chain length. Excretion in the urine amounted to about 85 % for C_{12} to about 60 % for C_{16} (Taylor et al., 1978).

α-Olefin sulfonates

With 73 % of the amount administered recovered in the urine after 5 days the α-olefin sulfonates are well absorbed in the gastrointestinal tract in rats (Inoue et al., 1982).

Dermal

Absorption by the percutaneous route is limited, since anionic surfactants tend to bind to the skin surface (Howes, 1975; Black & Howes, 1980).

Alkyl sulfates

Dermal penetration of ^{14}C-labeled $C_{12}ASO_4Na$ in guinea pigs amounted to 0.35 % of the applied dose of 3 µmol. This value was obtained by comparison of the total amount excreted after i.p. or dermal application of the compound (Prottey & Ferguson, 1975).

Alkane sulfonates

Dermal penetration of ^{14}C-labeled $C_{12}ASO_3Na$ in guinea pigs amounted to 0.2 % of the applied dose of 3 µmol. This value was obtained by comparison of the total amount excreted after i.p. or dermal application of the compound (Prottey & Ferguson, 1975).

Table 3-1: Data availability for toxicokinetics, metabolism and distribution

Compound		**Endpoints investigated**					**Reference**
Chain length	**Counter ion**	**Dermal Absorption**	**Oral Absorption**	**Distribution**	**Metabolism**	**Excretion**	
Alkyl sulphates							
C_{10}	K				+	+	Burke et al. (1975)
C_{11}	K		+		+	+	Burke et al. (1976)
C_{12}	K			+	+	+	Denner et al. (1969)
C_{12}	Na	+			+	+	Blank & Gould (1961); Howes (1975); Prottey & Ferguson (1975)
C_{16}	K				+	+	Merits (1975)
C_{16}	Na		+		+	+	Merits (1975)
C_{18}	Na		+	+	+	+	Burke et al. (1975)
Alkane sulfonates							
C_{12}	Na	+	+	+	+	+	Prottey & Ferguson (1975); Taylor et al. (1978)
α-Olefin sulfonates							
C_{14}	Na			+	+	+	Inoue et al. (1982)
C_{14}	Na	+					Minegishi et al. (1977)

α-Olefin sulfonates

About 0.6 % of 0.5 ml of 0.2 % aqueous ^{14}C-labeled C_{14}-α-olefin sulfonate (C_{14} ASO_3Na + C_{14} =/$OHASO_3Na$) was absorbed through rat skin in 24 hours, based on recovery in urine, bile and major organs. In another experiment, the compound was wiped off 0.5 hours after application. In this case absorption was lower and amounted to about 0.2 % of the dose. Furthermore, when skin integrity was damaged by removing the stratum corneum by applying 20 times an adhesive tape, about 50 % of the dose was recovered in urine, bile and major organs 30 hours after dermal application (Minegishi et al., 1977).

Distribution

Alkyl sulfates

After application of 14.4 mg/kg of the erythromycin salt of C_{16} ASO_4 to dogs or 250 mg/person to humans, radioactivity in plasma was maximal within 30 minutes to 2 hours of oral administration in both species indicating rapid absorption (Merits, 1975). The plasma concentration declined rapidly afterwards and reached 10 % of the maximum concentration after 6 hours, indicating rapid elimination.

Whole body autoradiography has been performed to follow the distribution of ^{35}S-$C_{10}ASO_4K$ (Burke et al., 1975), $C_{12}ASO_4$ K (Denner et al., 1969) and $C_{18}ASO_4K$ (Burke et al., 1975) or their metabolites within the body with time in experiments with rats after i.p. injection. For all compounds the only organs, where radioactivity was detected, were the liver and the kidney (Burke et al., 1975, 1976; Denner et al., 1969). The levels (not quantified) were highest 1 h after application. C_{10} AS was cleared from tissues more rapidly than C_{18}. After 6 hours, only traces of the C_{10} salt remained in the kidney, whereas it took 12 hours for the C_{18} salt to be cleared from the kidney (Burke et al., 1975; 1976).

Alkane sulfonates

The distribution of ^{35}S-$C_{12}ASO_3Na$ and ^{35}S-$C_{16}ASO_3Na$ has been studied in rats after dosing via gavage and i.p. administration by whole body autoradiography (Taylor et al., 1978). Accumulation of radioactivity after oral application was observed in liver and kidneys within 1 hour, but no general body distribution of radioactivity was observed with ^{35}S-$C_{12}ASO_3Na$. In contrast, after application of ^{35}S-$C_{16}ASO_3Na$ up to 2 hours after administration the radioactivity was mainly retained in the stomach and the gastrointestinal tract. Some cellular accumulation in the liver and kidneys was detected after 30 minutes. After i.p. application peak radioactivity in liver and kidneys were already observed after 15 to 30 minutes for both compounds.

α-Olefin sulfonates

After oral application of ^{14}C labelled C_{14}=/$OHASO_3Na$, blood concentrations peaked at 1-4 hours. The only organs with measurable radioactivity besides the gastrointestinal tract were liver and kidney (Inoue et al., 1982). The highest levels were obtained 1 hour after application with 0.492 % of dose per g tissue in the liver and 0.65 % of the dose/g tissue in the kidney after 4 h.

Metabolism and Excretion

Alkyl sulfates

Alkyl sulfates are extensively metabolized in rats, dogs and humans. This was tested with radiolabelled C_{10}, C_{11}, C_{12}, C_{16} and C_{18} alkyl sulfates, potassium salts (Denner et al., 1969; Burke et al., 1975, 1976; Merits 1975; Greb & Wingen, 1980).
The postulated mechanism is degradation involving ω-oxidation, followed by β-oxidation, to yield metabolites with chain lengths of C_2 and C_4 for even-chain carbon alkyl sulfates (Greb & Wingen, 1980). The major metabolite for even-chained alkyl sulfates was identified as the 4-carbon compound, butyric acid 4-sulfate. The 4-butyrolactone has been found as a minor metabolite which is also formed after application of butyric acid 4-sulfate (Ottery et al., 1970). Dog and human urine also contained one other minor metabolite, glycolic acid sulfate (Merits, 1975).

Metabolism of odd numbered chains (specifically, C_{11}) in rats was postulated to follow a similar ω, β degradation pathway: propionic acid-3-sulfate was the major urinary metabolite and pentanoic acid-5-sulfate and inorganic sulfate were minor metabolites (Burke et al., 1976).
The C_2 fragments enter the C_2 pool of the body and are either oxidized to CO_2 (Merits, 1975) or found in the body (Burke et al., 1975). In addition about 10 to 20 % of the dose usually is eliminated as inorganic sulfate (Denner et al., 1969; Burke et al., 1975; Merits, 1975). Table 3-2 gives an overview of the metabolites.

Table 3-2: Metabolites formed from alkyl sulfates with even chain length*

$HOOC-CH_2-CH_2-CH_2-OSO_3H$	$C_4-H_6-O_2$ 	$HOOC-CH_2OSO_3H$
butyric acid-4-sulfate	4-butyrolactone (ring structure)	Glycolic acid sulfate
Major Metabolite Found in rats, dogs, humans	Minor metabolite Found in rats, dogs, humans	Minor metabolite Found in dogs (and humans)

* investigated substances were potassium salts of C_{10}, C_{12}, C_{14} & C_{18} alkyl sulfates

The major path of excretion of the alkyl sulfates is the urine. Table 3-3 shows, that there are only minor differences for the alkyl sulfates of different chain lengths in the overall excretion after i.p. application. There are also no major differences in overall excretion between male and female rats or after oral, intraperitoneal or intravenous application (Denner et al., 1969; Burke et al., 1975, 1976). The rate of excretion in the urine, however, is somewhat different. After oral as well as i.p. application, excretion of the C_{12} compound is complete within 6 hours after application. In contrast the excretion amounts only to about 60 % (C_{10}), 40 % (C_{11}), 15 % (C_{18}) after i.p. application, and to 25 % for C_{11} or C_{18} 6 hrs after oral application. This indicates faster metabolism of the C12 compound than for the other chain lengths.

Lower amounts of the alkyl sulfates are excreted via the feces within 48 hrs after oral application for the C_{12}, C_{16} and C_{18} compounds. The lowest value was obtained for the C_{12}, while the highest values with considerable variation of 2.5 - 19.9 % (2 m, 2f) were found for C_{11}. In the bile from < 1 to 7.7 % (highest amount with C_{11}) of the dose applied was found up to 6 hours after i.v. application, indicating, that the amounts in the feces are mainly due to metabolism and not to unabsorbed compound. In addition the distribution of label in urine and feces from orally administered potassium dodecyl ^{35}S-sulfate (C_{12} $A^{35}SO_4$ K) was similar in both antibiotic-treated and untreated rats, indicating that the intestinal flora does not play a significant role in the metabolism of this compound (Denner et al., 1969).

Table 3-3: Influence of chain length on elimination of alkyl sulfates

Compound Shorthand	$C_{10}ASO_4K$ CAS 7739-63-1		$C_{11}ASO_4K$ CAS n.a.**		$C_{12}ASO_4K$ CAS 4706-78-9		$C_{18}ASO_4K$ CAS 7739-61-9	
Number of animals, sex*	3 m	3 f	3 m	3 f	6 m	6 f	3 m	3 f
Recovery from urine at 48 h (% of dose)*	82.9	79.5	98.2	90.6	86.3	93.2	77.1	73.9
Recovery from feces at 48 h (% of dose)*	1.2	1.0	2.5	7.3	0.2	0.9	1.1	2.6
Recovery from carcass at 48 h (% of dose)*	8.1	4.0	1.6	27.6	0.4	0.4	9.4	15.6
Reference	Burke et al. (1975)		Burke et al. (1976)		Denner et al. (1969)		Burke et al. (1975)	

* mean number of number of animals indicated, all values are mean values; ** n.a. = not available; 5 mg/kg bw of the ^{35}S labeled compounds was applied i.p. to MRC rats

Alkane sulfonates

The metabolism of alkyl sulfates and alkane sulfonates is similar. The biotransformation of alkane sulfonates (C_{12} and C_{16} have specifically been studied) also is assumed to involve ω-oxidation and β-oxidation. The major metabolite of the C_{12} and C_{16} is the analogous sulfonate butyric acid 4-sulfonate (Taylor et al., 1978; Black & Howes, 1980). However, in contrast to the alkyl sulfates no desulfonation of the molecule takes place. Table 3-4 compares the metabolism and elimination of a C_{12}-alkane sulfonate with a C_{12}-alkyl sulfate.
The excretion is mainly via the urine. The percentage in the feces (4.7 – 7.7 %) for the alkane sulfonate was somewhat higher than for the corresponding alkyl sulfate. In addition to the C_{12} compound also a C_{16} compound has been investigated (Taylor et al., 1978). Only the parent compound could be found in the feces which amounted to 37.1 - 46.4 % of the dose (2 male and female rats). Biliary secretion was less than 1 % of the dose. Therefore this reflects unresorbed compound.

Table 3-4: Comparison of elimination of alkyl sulfates and alkane sulfonates of same chain length

Compound	C_{12} ASO_4 K CAS 4706-78-9		C_{12} ASO_3 Na CAS 2386-53-0	
Number of animals, sex	3 m	3 f	3 m	4 f
Recovery from urine 48 hrs after application (% of dose)	98.7	106.9	95.7	87.4
Recovery from feces 48 hrs after application (% of dose)	0.7	0.5	4.7	7.7
Recovery from carcass (% of dose)	0.4	0.4	n.g.	n.g.
Inorganic sulfate in urine (% of dose)	17.9	18	n.d.	
Other metabolites	butyric acid 4-sulfate γ-butyrolactone		butyric acid 4-sulfonate	
Reference	Denner et al. (1969)		Taylor et al. (1978)	

n.g.: not given; n.d.: not detected; figures are mean values
5 mg/kg bw of the ^{35}S labelled compounds was applied by gavage to MRC rats

α-Olefin sulfonates

The metabolic fate of ^{14}C-labelled α-olefin sulfonate (^{14}C-AOS) was studied in rats by Inoue et al. (1982). Sodium tetradecene-1-^{14}C-sulfonate (a mixture of ^{14}C-sodium alkenyl(2)sulfonate and ^{14}C-sodium 3-hydroxy alkane sulfonate) was administered by single oral gavage and intravenous injection of 100 and 10 mg/kg bw, respectively. Within 24 hours after the oral dose, 72% of the dose was excreted in the urine, and 22 % in the feces, while the excretion in the bile was 4.3 % within 12 hours. The administered radioactivity was rapidly eliminated from the whole body within 24 hours. No intact ^{14}C-AOS was detected in any of the urine samples after oral and intravenous doses. The metabolite was apparently more polar than intact ^{14}C-AOS. Intact ^{14}C-AOS was shown to have the ability to bind with proteins, while the metaboites cannot. The metabolite was found to contain alcoholic, unsaturated and sulfonic acid functionalities, and it was therefore suggested that the metabolite is a hydroxylated or polyhydroxylated sulfonic acid of shorter chain length probably produced by ω-oxidation of the alkyl chain with subsequent β–oxidation. With this study, it was also demonstrated, that no accumulation of ^{14}C-AOS occurs.

Studies in Humans

In vitro Studies

Early studies with isolated human skin (not specified further) were unable to detect dermal penetration of C_{12} ASO_4 Na (Blank & Gould, 1961; Howes, 1975).

In vivo Studies

118 hrs after oral intake of 250 mg of the erythromycin salt of C_{16} ASO_4 by 2 human volunteers, the recoveries in urine and feces differed significantly. While one human excreted 80 % of the dose in the urine and 7 % in the feces, the other excreted 20 % in the urine and 73 % in the feces. The differences may be due to differences in absorption in the gastrointestinal tract (Merits, 1975). Metabolites identified included inorganic sulfate, butyric acid 4-sulfate and y-butyrolactone.

Conclusion

Alkyl sulfates, alkane sulfonates and α-olefin sulfonates are well absorbed after ingestion; penetration through the skin is however poor. After absorption, these chemicals are distributed mainly to the liver. Alkyl sulfates, alkane sulfonates and most probably also α-olefin sulfonates are metabolized by cytochrome P450-dependent ω-oxidation and subsequent ß-oxidation of the aliphatic fatty acids. End products of the oxidation are a C_4 sulfate or sulfonate (even numbered chain lengths) and a C_3 or C_5 sulfate or sulfonate (odd numbered chain lengths). For the alkyl sulfates, in addition sulfate is formed as a metabolite. The metabolites are rapidly excreted in the urine. Due to the low concentrations of the substances in consumer products and the limited uptake after dermal exposure which is the main route for consumers, a significant exposure of the developing foetus via the placenta, or the neonate via the breast milk is not likely.

3.1.2 Acute Toxicity

Studies in Animals

Inhalation

There were no data available.

Dermal

The individual results of available dermal acute toxicity studies are summarized in Table 3-5.

Alkyl sulfates

Alkyl sulfates have been used for decades and reliable studies on the acute dermal toxicity were carried out in the 1960s and 1970s. All of these studies have been performed with abraded and intact skin and a low number of animals in study. However, the limited documentation does not allow to judge whether abrasion affected the results.

Studies were available for C_{10-16} ASO_4 NH_4, C_{10-16} ASO_4 Mg, C_{12} ASO_4 Na and C_{12-13} ASO_4 K. The rabbit dermal LD_{50} values for the active substances were in the range of 200 to > 500 mg/kg bw (Carson & Oser, 1964; Procter & Gamble Co., 1975c, 1975d, 1978a). In these studies, described below in more detail, moderate to severe skin irritation and necrosis were observed in conjunction with decreases in body weight gain. The effects on body weights are thought to be caused by the general distress put on the animals by the skin lesions, and is therefore not considered as a sign of specific target toxicity.

C_{10-16} ASO_4 NH_4, C_{10-16} ASO_4 Mg, and C_{12-13} ASO_4 K were applied at 2 ml/kg bw as 23.5 – 25.1 % aqueous solutions to the intact and abraded skin of 3 rabbits/group for 24 hours under occlusive conditions (Procter & Gamble Co., 1975c, 1975d, 1978a). Treatment with C_{10-16} ASO_4 NH_4 and C_{10-16} ASO_4 Mg resulted in severe erythema and eschar formation. All sites were necrotic by day 2 or 5, respectively. At the end of 14 or 21 days, all necrotic tissue had sloughed off leaving the skin hyperpigmented. All except one animal lost weight during the course of the two studies. No other signs of systemic toxicity were observed. Treatment with C_{12-13} ASO_4 K resulted in moderate erythema, edema and eschar formation. By day 6, skin desquamation was observed, and some residual irritation was still present after 14 days. No signs of systemic toxicity were observed in the latter study. In none of the three studies there was any mortality. Hence, the LD_{50} was determined to be greater than 2 ml/kg (corresponding to about 500 mg active substance/kg bw).

Carson and Oser (1964) treated 10 male rabbits/group with a slurry of 33% aqueous C_{12} ASO_4 Na at 150, 300, 600, 1200 or 2000 mg/kg bw for 24 hours to both intact and abraded skin. Mortalities were 1/10, 2/10, 4/10, 8/10 and 10/10 animals in the 150, 300, 600, 1200 or 2000 mg/kg bw groups, respectively. Clinical signs included tremors, tonic-clonic convulsions, and respiratory failure. A decrease in body weights was seen during the 14 day post-dose observation period in animals dosed with 300 or 600 mg/kg bw. At necropsy, the treated skin area appeared leathery and showed slight scaling. The LD_{50} was about 600 mg/kg bw (corresponding to about 200 mg active substance/kg bw).

Alkane sulfonates

No data are available for alkane sulfonates but due to a comparable metabolism and effect concentrations in long-term studies the effects concentrations are expected to be in the same range as found for alkyl sulfates.

α-Olefin sulfonates

C_{14-16} =O/$HASO_3$ Na, as ca. 37 % aqueous solution, was tested according to OECD TG 402 in rats (Molins-kao S.A., 1986a) and in groups of 4 rabbits with intact and abraded skin by Ter Haar (1983). In the test with 2000 mg/kg bw of the aqueous solution according to OECD TG 402, there were no deaths and there was no indication for a systemic toxicity. The treatment only caused local effects such as erythema, edema, desquamation or hardened skin, which were completely reversible within 13 days. There were no pathological findings at necropsy. The dermal LD_{50} was greater than 6300 mg/kg, corresponding to about 2325 mg active substance/kg bw. The other study (Ter Haar, 1983), although poorly reported, does support the notion of a relatively low acute dermal toxicity of α-olefin sulfonates.

Oral

The individual results of available acute oral toxicity studies are summarized in the corresponding Table 3-6.

Alkyl sulfates

Acute oral LD_{50} values were available for 16 of the 21 HPV chemicals covered in this category. The LD_{50} values seemed to decrease with increasing chain lengths while the counter ion does not appear to influence the acute toxicity in a substantial way.

C_{10} ASO_4 Na was administered as 29-30% aqueous solution to 2-5 rats/sex/dose at dose levels of 1000 and 2000 mg/kg bw (Henkel KGaA, 1985a). Clinical signs included piloerection, diarrhea, paleness, blood in urine, and cramps. At necropsy, anemia of internal organs, peritionitis, and inflammation and hemorrhages in the gastrointestinal tract were found. The approximative LD_{50} was between 290 and 580 mg active substance/kg bw for females, and ca. 580 mg active substance/kg bw for males.

In studies performed with rats similarly to the (now deleted) OECD TG 401, the three tested ca. 25% aqueous solutions of C_{10-16} alkyl sulfates C_{10-16} ASO_4 NH_4, C_{10-16} ASO_4 Na and C_{10-16} ASO_4 had LD_{50} values of 1827, 1830 and 1780 mg active substance/kg bw (Procter & Gamble Co., 1975a; Procter & Gamble Co., 1974). The clinical signs were non-specific (decreased motor activity, decreased respiratory rate, abdominal cramps, diarrhea). Stomach ulcers were found at necropsy only in the study with C_{10-16} ASO_4.

While the LD_{50} in rats of the sodium salt of $C_{12}ASO_4$ was 1200 mg/kg bw in a study performed according to the now deleted OECD TG 401 (Henkel KGaA, 1983), the triethanolamine salt of $C_{12}ASO_4$ gave a rat LD_{50} of greater than 2000 mg/kg bw in a study performed similarly to OECD TG 420 (Kao Co., 1995). No clinical signs of toxicity and no pathological findings at necropsy were reported for the triethanolamine salt; the sodium salt caused decreased motor activity, decreased respiratory rate, and diarrhea. At necropsy, a hemorrhagic gastrointestinal tract was found in the succumbed animals, while no abnormal findings were reported for the animals that survived until the end of the observation period. The LD_{50} of the ammonium salt of $C_{12}ASO_4$ was reported to be greater than 135 mg/kg bw with no clinical signs of toxicity and no abnormal findings at necropsy (Stepan Co., 1980).

Acute oral toxicity tests performed in groups of male and female fasted rats with the sodium and triethanolamine salts of $C_{12-14}ASO_4$ resulted in a LD_{50} value of > 200 mg active substane/kg bw for both substances (Brown & Muir, 1970).

All other tested HPV chemicals of this sub-category (i.e., $C_{12-15}ASO_4Na$, $C_{12-16}ASO_4Na$, $C_{12-18}ASO_4Na$, $C_{14-18}ASO_4$ Na and $C_{16-18}ASO_4$ Na resulted in rat and/or mouse LD_{50}s greater than 2000

mg active substance/kg bw or, in the case of C_{14-18} & $_{16-18=}$ ASO_4Na greater than 5000 mg active substance/kg bw (Unilever Research 1975a, Henkel & Cie GmbH, 1976, Henkel KGaA, 1982, 1987g, 1989a, 1995; Procter&Gamble Co., 1972, 1974). In all these studies, only non-specific clinical signs of toxicity were observed (piloerection, lethargy, decreased motor activity and decreased respiratory rate, diarrhea). At necropsy, the major finings were irritations of the forestomach and gastrointestinal tract due to the irritating properties of the substances and anemia.

Alkane sulfonates

In a limit test, C_8 ASO_3 Na was administered at a dose level of 5000 mg/kg bw by gavage to 5 male and 5 female rats. No clinical signs of intoxication were observed, and no abnormal findings were reported at necropsy. The acute oral LD_{50} in rats was therefore greater than 5000 mg/kg bw (Stepan Co., 1985).

In a study on mice with a view to comparing the acute oral toxicities of the sodium salts of C_{15-18} alkane sulfonate (administered as 60 % aqueous solution) and C_{15-18} α-olefin sulfonate (administered as 38 % aqueous solution), practically identical LD_{50} values of 1440 and 1368 mg/kg bw were obtained for the two materials (Henkel KGaA, 1971). These data indicate a very similar range of oral acute toxicity LD_{50} values for the two sub-classes of this category.

α-Olefin sulfonates

C_{14-16} alpha-olefin sulfonate was tested in three different studies on rats with resulting LD_{50} values of 578 and 2200 mg active substance/kg bw, respectively (Hoechst AG, 1984b; Molins-kao S.A., 1986b). Necropsy of the animals that died in the first study (Hoechsst AG, 1984b) revealed a hemorrhagic mucosa of the stomach, dark red intestinal mucosa and liquid filled stomach, indicating severe irritation of the stomach and the gastrointestinal tract. No other abnormal pathology findings were reported in this and in the two other studies except for a pallor in the renal cortex in the succumbed animals of the study by Molins-kao S.A. (1986). In all three studies, the clinical signs of toxicity were non-specific, and included piloerection, squatting/lateral position, cyanosis, hypothermia, irregular breathing or decreased respiratory rate, and diarrhea.

The C_{14}-alpha-olefin sulfonate was tested in a study on mice and resulted in a LD_{50} value of 2430 mg/kg bw (Lion Co., 1969).

Studies in Humans

Data concerning acute toxicity in humans are not available.

Conclusion

Acute dermal LD_{50} values in rabbits were 200 mg/kg bw for the C_{12}- and greater than 500 mg/kg bw for the C_{12-13}- and C_{10-16}- alkyl sulfates, respectively; apart from moderate to severe skin irritation, clinical signs included tremor, tonic-clonic convulsions, respiratory failure, and body weight loss in the study with the C_{12}- alkyl sulfate and decreased body weights after administration of the C_{10-16}- alkyl sulfates. No specific systemic toxicity occurred in acute dermal toxicity studies with the α-olefin sulfonate C_{14-16}=/$OHASO_3$ Na on rats or rabbits at the highest tested dose level (740 mg/kg bw in rats, 2325 mg/kg bw in rabbits).

Acute oral LD_{50} values in rats and/or mice of alkyl sulfates were between 290 and 580 mg/kg bw for C_{10}-, between 1000 and 2000 mg/kg bw for C_{10-16}, and C_{12} greater than 2000 mg/kg bw for C_{12-14}, C_{12-15}, C_{12-16}, C_{12-18} and C_{18}, and greater than 5000 mg/kg bw for C_{16-18} alkyl sulfates. The counter ion does not appear to influence the toxicity in a substantial way. The clinical signs observed were non-specific (piloerection, lethargy, decreased motor activity and respiratory rate,

diarrhea). At necropsy the major findings were irritation of the gastrointestinal tract and anemia of inner organs. The LD_{50} in rats of the C_8 alkane sulfonate (sodium salt) was >5000 mg/kg bw with no clinical signs of intoxication and no adverse findings at necropsy reported. LD_{50} values in rats for the C_{14-16}-α-olefin sulfonates (sodium salts) were between 578 and 2200 mg/kg bw. Based on limited data, the acute oral LD_{50} values of alkane sulfonates and α-olefin sulfonates of comparable chain lengths are assumed to be in the same range.

No data were available for the inhalational route of exposure.

Table 3-5: Acute dermal toxicity studies in experimental animals (substances sorted by chain length; bold = HPV chemical)

Test substance	Test condition	Species	LD_{50}	Reference
ALKYL SULFATES				
C_{10-16} ASO_4 NH_4 **a.i.: 25.1 %** **CAS 68081-96-9**	6 animals (3 with intact, 3 with abraded skin), test substance applied undiluted at 2 ml/kg bw for 24 hrs under occlusion	rabbit (no further data)	> 2 ml/kg bw (corresponding to about 500 mg active substance/kg bw) No mortality; severe erythema and slight eschar formation at 24 hrs; necrosis by day 2 – 14 with sloughing of the skin by day 8 – 14; hyper-pigmentation of new skin by day 14; no signs of systemic toxicity; 1/3 rabbits with intact skin: decreased body weight (220 g) during 14 d observation period; necropsy: no data	Procter & Gamble Co. (1975c)
C_{10-16} ASO_4 Mg a.i.: 23.5 % CAS 68081-97-0	6 animals (3 with intact, 3 with abraded skin), test substance applied undiluted at 2 ml/kg bw for 24 hrs under occlusion	rabbit (no further data)	> 2 ml/kg bw (corresponding to about 500 mg active substance/kg bw) No mortality; severe erythema and eschar formation at 24 hrs; necrosis by day 5 – 21; necrotic tissues sloughed and leaving skin hyper-pigmented at day 21; weight loss in all except one rabbit; no further signs of systemic toxicity; necropsy: no data	Procter & Gamble Co. (1975d)
C_{12} ASO_4 Na **a.i.: ca. 33 %** **CAS 151-21-3**	10 males/group; application undiluted to intact and abraded skin at various dose levels for 24 hrs under occlusion	rabbit (no further data)	ca. 600 mg/kg bw (corresponding to about 200 mg active substance/kg bw) increased mortalitiy (10 - 100 %) at all dose levels (150 - 2000 mg/kg) tremors, tonic-clonic convulsions, respiratory failure; decrease in body weights; necropsy: leathery skin, scaling	Carson & Oser (1964)
C_{12-13} ASO_4 K a.i.: 25 % 91783-22-1	6 animals (3 with intact, 3 with abraded skin); test substance applied undiluted at 2ml/kg for 24 hrs under occlusion	rabbit (no further data)	> 2 ml/kg bw (corresponding to about 500 mg active substance/kg bw) No mortality; moderate to severe skin erythema, edema, atonia, eschar formation, desquamation by day 6, some residual skin irritation after 14 days, nasal discharge in two animals for 2 and 5 days, respectively; necropsy: large black lung patches in 1 animal; skin irritation.	Procter & Gamble Co. (1978a)
ALKANE SULFONATES				
no data available				
α-OLEFIN SULFONATES				
C_{14-16} =/$OHASO_3$ Na **a.i.: 37 %** **CAS 68439-57-6**	OECD TG 402 (24 hrs, occlusive)	rat (CFY; m/f)	> 2000 mg/kg bw (corresponding to 740 mg active substance/kg bw) No deaths; local effects such as erythema, edema, desquamation or hardened skin (complete recovery within 13 days after application); no signs of systemic toxicity; necropsy: no adverse findings	Molins-kao S.A. (1986a)

a.i.: active ingredient

Table 3-6: Acute oral toxicity studies in experimental animals (substances sorted by chain length; bold = HPV chemical)

Test substance	Test condition	Species	LD_{50} (for active ingredient)	Reference
ALKYL SULFATES				
C_{8-14} ASO_4 TEA a.i.: 46 – 49 % CAS 85665-45-8	single application of increasing doses via gavage; post dose observation period: 8 days; examined parameters: clinical signs	rat (Wistar; m)	> 3652 mg/kg bw apathy, abdominal position, decreased motility; necropsy: no data	Henkel & Cie GmbH (1970); Henkel KGaA (1999e)
C_{8-14} ASO_4 NH_4 a.i.: 33 % CAS 90583-10-1	single dosing with 5000 mg/kg bw via gavage; post dose observation period: 8 days; examined parameters: clinical signs	rat (Wistar; m)	> 1650 mg/kg bw apathy; necropsy: no data	Henkel & Cie GmbH (1972b)
C_{10} ASO_4 Na **a.i.: 29 – 30 %** **CAS 142-87-0**	2-5 animals/sex/dose, 1000 or 2000 mg/kg bw of the aqueous solution by single gavage	rat (SD; m/f)	Female: 290 – 580 mg/kg bw; male: ca. 580 mg/kg bw piloerection, diarrhea, abdominal position, paleness, blood in urine, cramps; necropsy: anemia of internal organs, inflammation/ hemorrhages in gastrointestinal tract, peritonitis	Henkel KGaA (1985a)
C_{10-16} ASO_4 NH_4 **a.i.: 25.1 %** **CAS 68081-96-9**	similar to the now deleted OECD TG 401	rat (Cox CD; m/f)	1827 mg/kg bw decreased motor activity and respiratory rate, blanching, abdominal griping and diarrhea; necropsy of survivors: no gross abnormalities	Procter & Gamble Co. (1975a)
C_{10-16} ASO_4 Na **a.i.: 25 %** **CAS 68585-47-7**	similar to the now deleted OECD TG 401	rat (Cox CD; m/f)	1830 mg/kg bw decreased motor activity and respiratory rate, abdominal griping and diarrhea, blanching, loss of corneal reflex and pupillary response; necropsy of survivors: no gross abnormalities	Procter & Gamble Co. (1974)
C_{10-16} ASO_4 a.i.: 25 % CAS 68611-55-2	similar to the now deleted OECD TG 401	rat (Cox CD; m/f)	1780 mg/kg bw decreased motor activity and respiratory rate, abdominal cramps and diarrhea; necropsy of survivors: sloughing of the endothelium and ulcers of the forestomach	Procter & Gamble Co. (1974)
C_{12} ASO_4 TEA **a.i.: no further data** **CAS 139-96-8**	similar to OECD TG 420, limit test on 5m/5f	rat (Wistar; m/f)	> 2000 mg/kg bw no clinical signs of intoxication and no adverse findings at necropsy	Kao Co. (1995)
C_{12} ASO_4 Na **a.i.: no further data** **CAS 151-21-3**	OECD TG 401 (now deleted)	rat (Wistar; m/f)	1200 mg/kg bw diarrhea, reduced activity, laboured breathing, coma; necropsy of animals that died during the study: hemorrhages in the gastrointestinal tract and vascular congestion in the liver; necropsy of survivors: no adverse effects	Henkel KGaA (1983)
C_{12} ASO_4 NH_4 **a.i.: 27 – 29 %** **CAS 2235-54-3**	single oral dosing with 0.5 ml/kg bw via gavage; post dose observation period: 14 days; examined parameters: clinical signs / necropsy	rat (SD)	> 135 mg/kg bw no clinical signs of intoxication; necropsy: organs of the thorax and abdomen appeared normal	Stepan Co. (1980)
C_{12-13} ASO_4 K a.i.: ca. 44 % CAS 91783-22-1	OECD TG 401 (now deleted)	rat (SD; m/f)	1700 mg/kg bw nasal discharge, lethargy; necropsy of animals that died during the study: changed colours of lung, kidney and livers; necropsy of survivors: pale lungs and mottled livers	Procter & Gamble Co. (1978b)

Test substance	Test condition	Species	LD_{50} (for active ingredient)	Reference
C_{12-14} ASO_4 Na **a.i.: 20 %** **CAS 85586-07-8**	Groups of fasted male and female animals were administered aqueous solutions containing 1000 or 2000 mg active substance/kg bw; post-dose observation period: 10 days	rat (m/f)	> 200 mg/kg bw diarrhea; necropsy: no data	Brown & Muir (1970)
C_{12-14} ASO_4 Na **a.i.: 30.2 %** **CAS 85586-07-8**	Unilever in-house protocol (similar to OECD TG 401)	mouse (m/f)	2600 mg/kg bw hypothermia, somnolence, signs of stress, wizened faces, laboured breathing, tremors; necropsy of animals that died during the study: irritation of the stomach and small intestine and slight irritation of the large intestine, pale livers and kidneys; necropsy of survivors: thickening of the stomach wall and enlargement of the mesenteric lymph node with small areas of cream material in the lymph node	Unilever Research (1977a)
C_{12-14} ASO_4 TEA **a.i.: 20 %** **CAS 90583-18-9**	Groups of fasted male and female animals were administered aqueous solutions containing 1000 or 2000 mg active substance/kg bw; post-dose observation period: 10 days	rat (m/f)	> 200 mg/kg bw diarrhea; necropsy: no data	Brown & Muir (1970)
C_{12-14} ASO_4 Mg a.i.: 22.2 % CAS 90583-23-6	P&G Standard Procedure #1 (similar to OECD TG 401)	rat (Cox CD; m/f)	2710 mg/kg bw decreased motor activity and respiratory rate, abdominal griping, piloerection, diarrhea, blanching, hemorrhagic rhinitis; necropsy of survivors: sloughing of the endothelium of the forestomach; adhesion of the forestomach to liver, diaphragm, peritoneum and spleen; ulcerations of varying sizes in the forestomach, sloughing of the endothelium of the glandular stomach	Procter & Gamble Co. (1975b)
C_{12-14} ASO_4 MEA a.i.: 30 – 31 % CAS 90583-16-7	single application of increasing doses via gavage; post dose observation period: 8 days; examined parameters: clinical signs	rat (Wistar; m)	1686 mg/kg bw reduced motility, abdominal position, laboured breathing; necropsy: no data	Henkel & Cie GmbH (1971)
C_{12-14} ASO_4 NH_4/TEA a.i.: no further data CAS 96690-75-4	single application of increasing doses via gavage; post dose observation period: 8 days; examined parameters: clinical signs	mouse (NMRI; m)	11200 mg/kg bw poor general health, dyspnoea, cramps, lateral position; necropsy: no data	Henkel & Cie GmbH (1972a)
C_{12-15} ASO_4 Na **a.i.: 31 %** **CAS 68890-70-0**	single application of increasing doses via gavage; post dose observation period: 21 days; examined parameters: clinical signs / necropsy	mouse (m/f)	2800 mg/kg bw somnolence, signs of stress, diarrhea; necropsy of animals that died during the study: gaseous/fluid distension and irritation of the stomach, gross irritation of the small intestine and pale kidneys; necropsy of survivors: thickening of the stomach wall	Unilever Research (1975d)
C_{12-15} ASO_4 Na **a.i.: 32 %** **CAS 68890-70-0**	single application of increasing doses via gavage; post dose observation period: 21 days; examined parameters: clinical signs / necropsy	mouse (m/f)	4300 mg/kg bw hypothermia, somnolence, signs of stress, diarrhea; necropsy of animals that died during the study: gaseous/ fluid distension of the stomach, gross irritation of stomach and small intestine, pale liver and kidneys; necropsy of survivors: thickening of the stomach wall	Unilever Research (1975b)

Test substance	Test condition	Species	LD_{50} (for active ingredient)	Reference
C_{12-15} ASO_4 Na **a.i.: 32.6 %** **CAS 68890-70-0**	single application of increasing doses via gavage; post dose observation period: 21 days; examined parameters: clinical signs / necropsy	rat (m/f)	3800 mg/kg bw somnolence, signs of stress, diarrhea; necropsy of animals that died during the study: gaseous distension of the stomach, irritation of the stomach and small intestine and protoporphyrin excretion around the nose in animals that died during the study; necropsy of survivors: no adverse effects	Unilever Research (1975a)
C_{12-15} ASO_4 Na **a.i.: 31 %** **CAS 68890-70-0**	single application of increasing doses via gavage; post dose observation period: 21 days; examined parameters: clinical signs / necropsy	mouse (m/f)	2900 mg/kg bw somnolence, signs of stress, diarrhea; necropsy of animals that died during the study: gaseous/fluid distension of the stomach, irritation of the small intestine and pale kidneys; necropsy of survivors: thickening of the stomach wall	Unilever Research (1975c)
C_{12-16} ASO_4 Na **a.i.: 87 %** **CAS 73296-89-6**	single application of increasing doses via gavage; post dose observation period: 8 days; examined parameters: clinical signs	mouse (CF 1 Wi 68; m)	2600 mg/kg bw apathy, abdominal position, coarse fur; necropsy: no data	Henkel & Cie GmbH (1976)
C_{12-18} ASO_4 Na **a.i.: no further data** **CAS 68955-19-1**	according to Directive 79/831/EEC, Annex V, part B.1	rat (Wistar; m/f)	> 2000 mg/kg bw no clinical signs of intoxication and no adverse findings at necropsy	Henkel KGaA (1989a)
C_{12-18} ASO_4 Na **a.i.: 25 %** **CAS 68955-19-1**	similar to the now deleted OECD TG 401	rat (Cox CD; m/f)	4010 mg/kg bw decreased motor activity and respiratory rate, blanching, abdominal griping, diarrhea, hemorrhagic rhinitis, slight loss of corneal reflex and pupillary response; necropsy of survivors: no adverse findings	Procter & Gamble Co. (1974)
C_{13-15} ASO_4 Na a.i.: 33 % CAS 86014-79-1	single application of increasing doses via gavage; post dose observation period: 21 days; examined parameters: clinical signs / necropsy	mouse (m/f)	2900 mg/kg bw hypothermia, signs of stress, somnolence; necropsy of animals that died during the study: gaseous/ fluid distension of the stomach, irritation of the small intestines, pale liver and kidneys; necropsy of survivors: slight thickening of the stomach wall	Unilever Research (1975j)
C_{14-18} ASO_4 Na **a.i.: 40 %** **CAS 68081-98-1**	similar to the now deleted OECD TG 401	rat (CD)	2752 – 7840 mg/kg bw decreased motor activity and respiratory rate, blanching, abdominal griping and diarrhea, loss of righting and corneal reflexes; necropsy: no data	Procter & Gamble Co. (1972)
C_{14-18} and C_{18}= ASO_4 Na a.i.: 57 – 60 % CAS 90583-31-6	OECD TG 401 (now deleted)	rat (Wistar; m/f)	> 1140 mg/kg bw no clinical signs of intoxication; necropsy: no adverse findings at macroscopic examination	Henkel KGaA (1992e)
C_{15-16} ASO_4 a.i.: 31.6 % CAS 99999-99-9	single application of increasing doses via gavage; post dose observation period: 21 days; examined parameters: clinical signs / necropsy	mouse (m/f)	6800 mg/kg bw hypothermia, cyanosis, signs of stress, diarrhea; necropsy of animals that died during the study: gross distension of the stomach and irritation of the stomach and small intestine; necropsy of survivors: thickening of the stomach wall	Unilever Research (1976b)
C_{16-18} ASO_4 Na **a.i.: 55 %** **CAS 68955-20-4**	according to Directive 79/831/EEC, Annex V, part B.1	rat (Wistar; m/f)	> 1100 mg/kg bw decreased motility and salivation; necropsy: no adverse findings	Henkel KGaA (1987g)
C_{16-18} ASO_4 Na **a.i.: 94.3 %** **CAS 68955-20-4**	OECD TG 401 (now deleted)	rat (Wistar)	> 1886 mg/kg bw no clinical signs of intoxication and no adverse findings at necropsy	Henkel KGaA (1995)

Test substance	Test condition	Species	LD_{50} (for active ingredient)	Reference
C_{14-18} and $_{16-18}$= ASO_4 Na a.i.: 55 % CAS 85681-68-1	single application of increasing doses via gavage; post dose observation period: 14 days; examined parameters: clinical signs / necropsy	rat (Wistar; m)	5500 mg/kg bw diarrhea, piloerection, increased breathing; necropsy: no adverse findings at macroscopic examination	Henkel KGaA (1982)
ALKANE SULFONATES				
C_8 ASO_3 Na **a.i.: no further data** **CAS 5324-84-5**	16 CFR 1500.3	rat (SD; m/f)	> 5000 mg/kg bw no clinical signs of intoxication; necropsy: no adverse findings at macroscopic examination	Stepan Co. (1985)
C_{15-18} ASO_3 Na a.i.: 60 % CAS 68815-15-6	single application of increasing doses via gavage; post dose observation period: 8 days; examined parameters: clinical signs	mouse (CF1; m)	1440 mg/kg bw apathy, abdominal position, piloerection; necropsy: no data	Henkel KGaA (1971)
α-OLEFIN SULFONATES				
C_{14} =/$OHASO_3$ Na **a.i.: no further data** **CAS 93686-14-7**	single application of increasing doses via gavage; post dose observation period: 7 days; examined parameters: clinical signs	mouse (dds; m)	2430 mg/kg bw slight loose passage; necropsy: no data	Lion Co. (1969)
C_{14-16} =/$OHASO_3$ Na **a.i.: 25 %** **CAS 68439-57-6**	OECD TG 401 (now deleted)	rat (Wistar; m/f)	578 mg/kg bw squatting/lateral position, clonic cramps, cyanosis, hypothermia or irregular breathing; necropsy of animals that died during the study: stomach filled with brown liquid, dark red stomach mucosa with hemorrhages and dark red intestine mucosa in animals that died during the study; necropsy of survivors: no adverse findings at macroscopic examination	Hoechst AG (1984b)
C_{14-16} =/$OHASO_3$ Na **a.i.: 37 %** **CAS 68439-57-6**	OECD TG 401 (now deleted)	rat (SD; m/f)	2220 mg/kg bw piloerection, hunched posture, abnormal gait, lethargy, decreased respiratory rate, diarrhea, increased salivation, pallor of the extremities, ptosis; necropsy of animals that died during the study: pallor of the renal cortex; necropsy of survivors: no adverse findings at macroscopic examination	Molins-kao S.A. (1986b)
C_{15-18} =/$OHASO_3$ Na a.i.: 38 % CAS 91082-14-3	single application of increasing doses via gavage; post dose observation period: 8 days; examined parameters: clinical signs	mouse (CF1; m)	1368 mg/kg bw apathy, abdominal position, piloerection; necropsy: no data	Henkel KGaA (1971)

a.i.: active ingredient

3.1.3 Irritation

Skin Irritation

Studies in Animals

Results of skin irritation studies with rabbits are summarized in Table 3-7.

Alkyl sulfates

Reliable skin irritation tests in rabbits have been performed with the sodium salt of C_{12}- and the sodium and triethanolamine salts of C_{12-14}-alkyl sulfates, with C_{12-16} ASO_4 NH_4, and with C_{16-18} ASO_4 Na. Only three materials, i.e., C_{12} ASO_4 Na, C_{12-14} ASO_4 Na and C_{16-18} ASO_4 Na were subjected to protocols in accordance with the current testing guideline (OECD TG 404), i.e., with 0.5 ml of the test substance, an exposure time of 4 hours, and under semi-occlusive conditions. It is therefore difficult to make a direct comparision between the test results, as an open or occlusive application may have influenced the outcome of the studies. For the following evaluation, only studies using the same protocol were therefore used. Additional studies are listed in the table below for the purpose of information.

In skin irritation tests performed on rabbits in accordance with OECD TG 404, the C_{8-14}-, C_{8-16}, C_{12-14}- (tested at 90% in water), and the C_{14-18}- alkyl sulfates were all corrosive. If tested at a concentration of 25%, the C_{12-14}- alkyl sulfate was only irritant, even under (worst-case) occlusive conditions (Henkel KGaA (1987c, 1999f). At ≥ 7%, C_{13-15}-alkyl sulfates were strong irritants, and, at 5%, C_{12}-, C_{12-15}-, and C_{15-16} –alkyl sulfates were moderate to strong irritants. At concentrations up to 31.5%, C_{16-18} ASO_4 Na showed only slight irritation.

The level of detail reported in some studies does not allow a sound scientific evaluation of the irritant potential (e.g., when important details, such as the test concentration have not been stated). These studies are therefore not discussed in the text but are only listed in the table below for information sake and are marked with a reliability score of "4".

Table 3-7: Results of different studies on skin irritation in rabbits and guinea pigs (substances sorted by chain length; bold = HPV chemical)

Test substance	Test conditions	Results	Reliability	Reference
ALKYL SULFATES				
C_{8-14} ASO_4 NH_4 a.i.: 32.9 % CAS 90583-10-1	OECD TG 404 (4h, semi-occlusive)	Corrosive	1	Henkel KGaA (1991h)
C_{8-16} ASO_4 Na a.i.: 29 – 31 % CAS 90583-27-0	OECD TG 404 (4h, semi-occlusive)	Corrosive	1	Henkel KGaA (1991e)
C_{12} ASO_4 Na a.i.: 25 % CAS 151-21-3	4 h, occlusive	Severely irritating (PII: 7.73)	2	Henkel KGaA (1987c)
C_{12} ASO_4 Na a.i.: 5 % CAS 151-21-3	similar to OECD TG 404 (4 h, semi-occlusive)	Moderately to strongly irritating	2	Unilever Research (1982)
C_{12} ASO_4 TEA a.i.: 40% CAS 139-96-8	Open Patch test	moderately irritating (PII: 4.92)	2	Procter & Gamble Co. (1976a)
C_{12} ASO_4 TEA a.i.: no further data CAS 139-96-8	Open Patch test	moderately irritating (PII: 4.67)	2	Procter & Gamble Co. (1976b)

Test substance	Test conditions	Results	Reliability	Reference
C_{12-14} ASO_4 Na **a.i.: 90 %** **CAS 85586-07-8**	OECD TG 404 (4h, semi-occlusive)	Corrosive	1	Henkel KGaA (1994)
C_{12-14} ASO_4 TEA **a.i.: 25 %** **CAS 90583-18-9**	4h, occlusive	Severely irritating (PII: 5.8)	2	Henkel KGaA (1987c, 1999f)
C_{12-14} ASO_4 Mg a.i.: 30.5 % CAS 90583-23-6	4h, occlusive	Severely irritating (PII: 7.9)	2	Henkel KGaA (1987e)
C_{12-15} ASO_4 Na **a.i.: 5 %** **CAS 68890-70-0**	similar to OECD TG 404 (4 h, semi-occlusive)	strongly to severely irritating	2	Unilever Research (1982)
C_{12-16} ASO_4 NH_4 **a.i.: 30 %** **CAS 90583-12-3**	4h, occlusive	Severely irritating (PII: 7.4)	2	Henkel KGaA (1987a)
C_{13-15} ASO_4 Na a.i.: 1 – 30.5 % CAS 86014-79-1	similar to OECD TG 404 (4 h, semi-occlusive)	1 %: slightly irritating 3 – 5 %: slightly - moderately irritating 7 ,10, 15, 30.5 %: strongly irritating	2	Unilever Research (1983a)
C_{14-18} and C_{18}= ASO_4 Na a.i.: 57 – 60 % CAS 90583-31-6	OECD TG 404 (4h, semi-occlusive)	Corrosive	1	Henkel KGaA (1991b)
C_{15-16} ASO_4 a.i.: 5 % CAS 99999-99-9	similar to OECD TG 404 (4 h, semi-occlusive)	moderately irritating	2	Unilever Research (1982)
C_{16-18} ASO_4 Na **a.i.: 25 %** **CAS 68955-20-4**	4h, occlusive	Moderately irritating (PII: 2.33)	2	Henkel KGaA (1987c)
C_{16-18} ASO_4 Na **a.i.: 5 – 31.5 %** **CAS 68955-20-4**	similar to OECD TG 404 (4 h, semi-occlusive)	5 %: slight effects 10 – 31.5 %: slight to moderate effects	2	Unilever Research (1983b)
ALKANE SULFONATES				
no data available				
α-OLEFIN SULFONATES				
C_{14-16} =/OHASO_3 Na **a.i.: ca. 40 %** **CAS 68439-57-6**	OECD TG 404 (4h, semi-occlusive)	Irritating	2	Hoechst AG (1988b)
C_{14-18} =/OHASO_3 Na **a.i.: 5 %** **CAS 863609-89-6**	Draize test open (3 * 0.2 ml on 3 consecutive days) Study with guinea pigs	Very slightly irritating	2	Lion Co. (1978a)
C_{14-18} =/OHASO_3 Na **a.i.: 15 %** **CAS 863609-89-6**	Draize test open (3 * 0.2 ml on 3 consecutive days) Study with guinea pigs	Very slightly irritating	2	Lion Co. (1978b)
C_{14-18} =/OHASO_3 Na **a.i.: 5 or 10 %** **CAS 863609-89-6**	Draize test Open Study with guinea pigs	5 %: not irritating 10 %: very slightly irritating	4	Lion Co. (1989)

PII: primary irritation index (maximum score = 8.0)

Influence of chain length

Skin irritation tests at concentrations≥ 25% resulted, independent of the chain length, all in severe irritation or even corrosion, with the only exception of the C_{16-18} ASO_4Na which showed only slight to moderate effects at a concentration of 31.5% in water (Henkel KGaA, 1991e, 1991h, 1994; Unilever Research, 1982, 1983a, 1983b). The available data do not allow the conclusion that there is a correlation between chain length and irritancy potential because the results were obtained by testing mixtures rather than discrete chain lengths and at high concentrations were most alkyl sulfates are severely irritating or corrosive. No comparative skin irritation studies using

alkylsulfates of discrete chain lengths and identical concentrations are available. However, various authors have investigated the influence of sodium alkyl sulphate chain length on skin parameters like transepidermal water loss (Wilhelm et al., 1993), epidermal electrical conductance (Dugard & Scheuplein, 1973), skin swelling (Choman, 1961; Schulz & Rose, 1957), extraction of amino acids and proteins (Prottey & Ferguson, 1975) and development of erythema in human volunteers (Kligman & Wooding, 1967; Wilhelm et al., 1993). All these studies consistently show a maximum of reactions at chain length C12. Therefore, C_{12} ASO_4Na can be taken as the worst case representative for the skin irritation of alkyl sulfates in general.

Influence of counter ion

Ciuchta & Dodd (1978) studied various methods to assess the skin irritating properties of surfactants; the sodium, ammonium and triethanolamine salts of lauryl sulfate ($C_{12}ASO_4$) were included in this study and evaluated by the Draize test (see Table 3-8). The following primary irritancy indices (PII) were obtained, indicating a slightly higher irritancy of the ammonium and sodium salts as compared to the triethanolamine salt:.

Table 3-8: Counter ion effects on primary skin irritation of $C_{12}ASO_4$

$C_{12}ASO_4$-concentration (%)	PIIs in rabbits after 24 h occluded patch		
	Counter ion		
	Na	NH_4	TEA
2	5-5.5	5.2	3.5
10	6	5.8	5
20	6	6	5.2

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

At concentrations of about 40%, C_{14-16} =/$OHASO_3$ Na was irritating in a study performed according to OECD TG 404 (Hoechst AG, 1988b; no details available. At 5 %, C_{14-18} =/$OHASO_3$ Na was very slightly irritating in rabbits when applied on three consecutive days. A single, open application of this substance at a concentration of 5 % was not irritating to the skin of guinea pigs (Lion Co., 1978a, 1978b, 1989).

Studies in Humans

Alkyl sulfates

A repeated-four hour human patch test was conducted with 20 % C_{12} ASO_4 Na (Procter and Gamble, 1998b). To avoid unacceptably strong reactions, the study involves a graduated exposure format in which occlusive patch application times are gradually increased in time at naïve sites until either positive irritation response is observed or the maximum time is reached. C_{12} ASO_4 Na was included as the positive control in the study. During the first week of the study, patches are moved to naïve sites on the back after the patch application and graded 24, 48 and 72 hours later (eg, Day 1: 5 min patch application. Day 2: grade response from Day 1; then apply 15 min patch. Day 3: grade responses from Days 1 and 2; then apply 30 min patch. Day 4: grade responses from Days 1-3 and apply 120 min patch). Based on the results from Week 1, 120 min patch application was selected for Week 2.

For the second week, subjects are patched daily for four consecutive days for 120 min, until the patch site exhibits a positive reaction. Any reaction greater than (+) is considered positive and the volunteer is not further exposed. Eight volunteers had a grade of 0 after the second repeated patch applilcation, ten had grades of (+), three had grades of (++). After the third repeated patch application, seven volunteers had grades of (+) and one had a grade of (++). This demonstrates that repeated, 120 min, occlusive patch applications are irritating, but not corrosive to human volunteers.

This method has also been evaluated for inter and intralaboratory variability for assessing skin irritation. In those studies, up to 20% C_{12} ASO_4 Na has been evaluated. (Griffiths et al, 1997; Robinson et al, 1998; Basketter et al, 2004). Not only has the method been shown to be reproducible, but up to 20 % C_{12} ASO_4 Na has been consistently shown to be the concentration that causes irritation in humans. Skin irritation responses in humans are normally comparative. The use of 20 % SDS (C_{12} ASO_4 Na) provides an internal calibration check on any given irritation study.

Conclusion

In skin irritation tests performed on rabbits in accordance with OECD TG 404, the ca. 30% aqueous solutions of C_{8-14}- and C_{8-16}, the 90% solution of C_{12-14}-, and the 60% solution of $C_{14-18/18=}$-alkyl sulfates were all corrosive. At 25%, and under occlusive conditions, C_{12}- and C_{12-14}- and at ≥ 5-7% C_{12}-, C_{12-15}-, C_{13-15}- and C_{15-16} –alkyl sulfates were moderate to strong irritants. C_{16-18} ASO_4 Na showed only slight irritation up to concentrations of 31.5 %. Comparative studies investigating skin effects like transepidermal water loss, epidermal electrical conductance, skin swelling, extraction of amino acids and proteins or development of erythema in human volunteers consistently showed a maximum of effects with C_{12} ASO_4Na. Shorter and longer chain lengths had less strong effects. Different counter-ions did not significantly influence the degree of skin irritation.

In contrast to the available animal studies, the most irritating alkyl sulfate is moderately irritating in humans at a concentration of 20 %. In the human repeated 4-hour patch test, 20 % C_{12} ASO_4 Na is routinely used as the positive control material as a material well documented to produce an irritant response under occlusive patch conditions. With C_{12} ASO_4Na being the most irritant alkyl sulfate it can be concluded that in humans 20 % is the threshold concentration for irritative effects of alkyl sulfates in general. The α-olefin sulfonate C_{14-16} =/$OHASO_3$ Na was irritating when tested at a concentration of 40% according to OECD TG 404. 5 % of an α-olefin sulfonate (C_{14-18} =/$OHASO_3$Na) were only very slightly irritating. No data were available with regard to the skin irritation potential of alkane sulfonates. Based on the similar chemical structure they are assumed to exhibit similar skin irritation properties as AS or AOS of comparable chain lengths.

Eye Irritation

Studies in Animals

The results of eye irritation studies with rabbits are summarized in Table 3-9.

Alkyl sulfates

C_{12} ASO_4 Na (as 25 % aqueous solution), $C_{12-16,}ASO_4$ NH_4 (as 30 % and 10 % aqueous solution), C_{16-18} ASO_4 Na (25 % aqueous solution), C_{12-14} ASO_4 Mg (10 % aqueous solution), and C_{12-16} ASO_4 TEA (25 % aqueous solution) were all tested in studies performed in accordance with OECD TG 405. In these studies, the 25% aqueous solution of C_{16-18} ASO_4 Na was only mildly irritating, and the 10% solution of $C_{12-16,}ASO_4$ NH_4 was irritating (Henkel KGaA, 1987i, 1987l), while all

other materials induced severe eye irritation with corneal effects still present at study end (Henkel KGaA, 1987i, 1988c).

Influence of chain length

From the results reported in reliable tests (see Table 3-9) it appears, that the irritating potential decreases with increasing alkyl chain length. In studies using the same test protocol, i.e., the OECD TG 405, only mild irritation was observed with C_{16-18} ASO_4 Na, while at comparable test concentrations irreversible effects were caused by C_{12-16} – and C_{12} –alkyl sulfates (Henkel KGaA, 1987i, 1988c). In a comparative, non-Guideline study according to Draize, a homologous series of alkyl sulfates of chain lengths from C8 to C18 was tested in rabbits and just like for skin irritation a maximum of irritative effects was observed at C12 (Daweke, 1959).

Influence of counter ion

The eye irritation in the Draize test produced with the ammonium, triethanolamine and sodium salts of lauryl sulfate ($C_{12}ASO_4$) was similar (Ciuchta & Dodd, 1978). Studies performed with C_{12-16} ASO_4 NH_4 or C_{12-16} ASO_4 TEA also indicate no influence of the ammonium and triethanolamine counter ion on the irritancy (Henkel KGaA, 1987i, 1988c). For C_{12-18} ASO_4, no differene was observed with regard to potassium and sodium as counter ion (Henkel KGaA, 1985b, 1985c). Therefore, the counter ion is not considered to have a relevant influence on the eye irritating properties of the alkyl sulfates of this category.

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

In a study performed in accordance with OECD TG 405, C_{14-16} =/$OHASO_3$ Na was applied as moistened powder (100 mg) to the eyes of 3 rabbits. All animals showed severe eye irritation with severe cornea effects still present at the end of the observation period in two animals (Hoechst AG, 1984a). Eye irritation was observed in a further study according to OECD TG 405, in which C_{14-16} =/$OHASO_3$ Na was tested at 40%; all effects were fully reversible within 7 days (Hoechst AG, 1988c).

Eye irritation studies were conducted on groups of six rabbits according to the method of Draize. The data show that concentrated C_{14-16} α-olefin sulfonate (pH 7-8) is a severe eye irritant. Although high scores for corneal, iris, and conjunctival effects were still present at 72 hours, the response was reversible (Ter Haar, 1983).

Slight eye irritation was observed in Draize tests with 0.1 ml of C_{10}, C_{12}, C_{14}, C_{16}- and C_{18} - α-olefin sulfonates at a concentration of 1 and 5%. All effects were fully reversible within 96 hours after the application (Iimori, 1972).

Table 3-9: Results of studies on eye irritation in experimental animals (substances sorted by chain length; bold = HPV chemical)

Test substance	Protocol	Results	Reliability	Reference
ALKYL SULFATES				
C_{8-14} ASO_4 NH_4 a.i.: 0.5 – 20 % CAS 90583-10-1	Draize test	< 5 %: not irritating ≥ 5 %: moderately irritating	2	Henkel KGaA (1977b)
C_{12} ASO_4 Na **a.i.: 25 %** **CAS 151-21-3**	OECD TG 405	irreversible effects	1	Henkel KGaA (1987i)

Test substance	Protocol	Results	Reliability	Reference
C_{12} ASO_4 NH_4 a.i.: 2 – 20 % CAS 2235-54-3	Draize test	2 %: not irritating 10, 20 %: irritating	2	Ciuchta & Dodd (1978)
C_{12} ASO_4 TEA a.i.: 1.25 – 20 % CAS 139-96-8	Draize test	1.25 %: not irritating ≥ 2.5 %: irritation especially when the eyes were not rinsed; within 7 days nearly all observed signs of irritation disappeared	2	Serrano et al. (1977)
C_{12} ASO_4 TEA a.i.: 2 – 20 % CAS 139-96-8	Draize test	2 %: not irritating 10, 20 %: irritating	2	Ciuchta & Dodd (1978)
C_{12-14} ASO_4 Na a.i.: 5 – 20 % CAS 85586-07-8	Draize test	≥ 5 %: highly irritating 20%: effects not reversible	2	Henkel KGaA (1979)
C_{12-14} ASO_4 Na a.i.: 5 % CAS 85586-07-8	Draize test	moderately irritating	2	Unilever Research (1976k)
C_{12-14} ASO_4 MEA a.i.: 0.5 – 20 % CAS 90583-16-7	Draize test	≤ 10 %: not irritating 20 %: slightly irritating	2	Henkel KGaA (1977b)
C_{12-14} ASO_4 Mg a.i.: 10 % CAS 90583-23-6	OECD TG 405	irreversible effects	1	Henkel KGaA (1987l)
C_{12-14} ASO_4 TEA a.i.: 25 % CAS 90583-18-9	OECD TG 405	irreversible effects	1	Henkel KGaA (1987i)
C_{12-15} ASO_4 Na a.i.: 5 % CAS 68890-70-0	Draize test	moderately irritating	2	Unilever Research (1975g)
C_{12-16} ASO_4 Na a.i.: 0.5 – 20 % CAS 73296-89-6	Draize test	≤ 1 %: not irritating ≥ 5 %: moderately irritating 10, 20%: effects not reversible	2	Henkel KGaA (1977b)
C_{12-16} ASO_4 NH_4 a.i.: 10 % CAS 90583-12-3	OECD TG 405	Irritating	1	Henkel KGaA (1987l)
C_{12-16} ASO_4 NH_4 a.i.: 30 % CAS 90583-12-3	OECD TG 405	irreversible effects	1	Henkel KGaA (1988c)
C_{12-18} ASO_4 Na a.i.: 0.5 – 20 % CAS 68955-19-1	Draize test	≤ 1 %: not irritating ≥ 5 %: moderately irritating 10, 20%: effects not reversible	2	Henkel KGaA (1977b);Kaestner & Frosch (1981)
C_{12-18} ASO_4 Na a.i.: 5 % CAS 68955-19-1	Draize test	moderately irritating	2	Henkel KGaA (1985b, 1985c)
C_{12-18} ASO_4 K a.i.: 5 % CAS 90583-24-7	Draize test	moderately irritating	2	Henkel KGaA (1985b, 1985c)
C_{13-15} ASO_4 Na a.i.: 5 % CAS 86014-79-1	Draize test	moderately irritating	2	Unilever Research (1975h)
C_{15-16} ASO_4 a.i.: 5 % CAS 99999-99-9	Draize test	moderately irritating	2	Unilever Research (1976l)
C_{16-18} ASO_4 Na a.i.: 25 % CAS 68955-20-4	OECD TG 405	moderately irritating	1	Henkel KGaA (1987i)
C_{16-18} ASO_4 Na a.i.: 5 % CAS 68955-20-4	Draize test	slightly to moderately irritating	2	Unilever Research (1975i)
C_{16-18} ASO_4 Na a.i.: 5 % CAS 68955-20-4	Draize test	moderately irritating	2	Unilever Research (1976k)

Test substance	Protocol	Results	Reliability	Reference
ALKANE SULFONATES				
no data available				
α-OLEFIN SULFONATES				
C_{10}, C_{12}- C_{14}, C_{16}, C_{18} =/$OHASO_3$ Na a.i.: 0.01 – 5 %	Draize test	0.01, 0.05, 0.1, 0.5%: not irritating 1, 5%: slightly irritating All effects fully reversible within 96 hours	2	Iimori (1972)
C_{14-16} =/$OHASO_3$ Na a.i.: 40 % CAS 68439-57-6	OECD TG 405	irritating; all effects reversible within 7 days	1	Hoechst AG (1988c)
C_{14-16} =/$OHASO_3$ Na a.i.: 90 % CAS 68439-57-6	OECD TG 405	Severely irritating, irreversible effects (cornea, conjunctivae) in two out of three animals at the end of the observation period (21 days)	1	Hoechst AG (1984a)
C_{14-16} =/$OHASO_3$ Na a.i.: 20-40% CAS 68439-57-6	Draize test	Severely irritating; effects on cornea, iris and conjunctivae; all effects reversible	2	Ter Haar (1983)

Studies in Humans

There are no data available.

Conclusion

C_{12}-containing alkyl sulfates (at concentrations ≥ 10%) were severely irritating to the eyes of rabbits and caused irreversible corneal effects. With increasing alkyl chain length, the irritating potential decreases, and $C_{16-18}ASO_4Na$, at a concentration of 25%, was only a mild irritant. Concentrated C_{14-16}- α-olefin sulfonates were severely irritating, but caused irreversible effects only if applied as undiluted powder. At concentrations below 10 % mild to moderate, reversible effects were found. No data were available for alkane sulfonates.

3.1.4 Sensitization

Studies in Animals

Studies on sensitization are summarized in the corresponding Table 3-10.

Alkyl sulfates

Alkyl sulfates were not sensitizing in various studies, including adjuvant (guinea pig maximization tests) and non-adjuvant (Buehler test) protocols in accordance with OECD TG 406.

In the Local Lymph Node Assay (LLNA) performed in accordance with OECD TG 429, C_8 ASO_4 Na was not sensitizing in female CBA/J mice (Procter & Gamble Co., 1992b). C_{12} ASO_4 Na gave positive reactions (i.e., it induced an increase in cell proliferation) in two out of three LLNAs (Ikarashi et al., 1993; Basketter et al., 1994; Montelius et al., 1994). As discussed by Montelius et al. (1994), the observed positive reactions were due to a non-antigen-specific proliferative stimulus induced by the irritating effect of the tested concentrations (4, 5, 10 and 25%). The difference in the results between different studies could be caused by the fact that preparations of different quality from different manufacturers show a marked variation in their irritating properties (Agner et al., 1989 as quoted in Montelius et al., 1994). According to Basketter et al. (1994) and Basketter (2002), C_{12} ASO_4 Na causes Langerhans' cell migration from the epidermis to draining lymph nodes with a consequent transient increase in cell proliferation. Subsequent cell typing studies have shown the lymph node cell changes to be characteristic of irritancy and not of allergy (Basketter, 2002).

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

C_{14-16} =/$OHASO_3$ Na was not sensitizing in a guinea pig maximization test (GPMT) that was performed in accordance with OECD TG 406. Animals were induced by giving three single 0.1 ml intradermal injections of Freund's Complete Adjuvant (FCA), the test substance in a (not specified) vehicle and the test substance emulsified in the adjuvant. One week later, these animals were induced again by topical application of the test substance in the test vehicle. Two weeks later the animals were challenged with the highest non-irritating concentration (not specified further). Formalin was used as the positive control, and sodium lauryl sulfate was used as the negative control (Ter Haar, 1983).

C_{14} =/$OHASO_3$ Na was not sensitizing in a maximization test performed on male guinea pigs according to OECD TG 406. The sensitivity of the experimental method was verified by use of a positive control group treated with dinitrochlorobenzene (DNCB, 1%) (Lion Co., 2004b). In an earlier study (Lion Co., 1978c), groups of 15 guinea pigs were tested in a maximization test with the magnesium salts of C_{14}-,C_{16}- and C_{18} alkane and alkene sulfonic acids (1:1:1 mixture). None of the animals showed an allergic reaction.

It is noted that a sensitizing impurity (1,3-sultone) could on occasion be present in α-olefin sulfonates when proper manufacturing practices were not followed (Ter Haar, 1983).

Studies in Humans

Alkyl sulfates

C_8 ASO_4 Na was not sensitizing in 5 different Repeat Insult Patch Tests with groups of 95 – 116 volunteers and concentrations of 0.1, 0.3 or 0.5 % (Procter & Gamble Co., 1993b, 1993c, 1994a, 1994b, 1994c). C_{16-18} ASO_4 Na was also tested negative in a Repeat Insult Patch Test with 86 volunteers at a concentration of 0.25 % (Procter & Gamble Co., 1991a). In another Repeat Insult Patch Test, C_{12} ASO_4 NH_4 was tested negative in 98 volunteers at a concentration of 4 % (Procter & Gamble Co., 1996c).

Cases of reported contact sensitization to sodium lauryl sulfate (C_{12} ASO_4 Na) have been reviewed by Rietschel and Fowler (2001) and by Dooms-Goossens and Blockeel (1996). A few, positive reactions were usually seen under conditions where also other, possibly sensitizing agents were used, or on compromised skin. Irritancy was often difficult to exclude. It was concluded by Rietschel and Fowler (2001) that "sodium lauryl sulfate is a skin irritant and comedogenic agent but is not usually a sensitizer". Given the widespread use of alkyl sulfates in consumer products, the very low incidence of reported cases indicates that the sensitizing potential of alkyl sulfates is very low.

Alkane sulfonates

One case of allergic contact conjunctivitis from synthetic detergents containing lauryl alkane sulfonate ($C_{12}ASO_3$ Na) tested at 0.1% was reported (Orlandini et al., 1990 as quoted in Dooms-Goossens and Blockeel, 1996).

α-Olefin sulfonates

C_{14-16} =/$OHASO_3$ was not sensitizing in a Draize test with 88 human volunteers. The test was performed with 8 commercial samples (8 % in water). Due to considerable irritation, the final

challenge was made at 4 %. 10 occlusive applications were made to the same site at the rate of three times weekly (48 hrs during the week and 72 hrs on weekend). Then there followed a rest (incubation) period followed by a 72 hr final elicitation at a fresh site (Ter Haar, 1983).

Conclusion

Based on the available data in experimental animals as well as from data in humans, alkyl sulfates and α-olefin sulfonates will give no concern for skin sensitizing properties. No reliable data are available for the alkane sulfonates. Based on the similar chemical structure, no sensitization is expected.

Table 3-10: Results of studies on skin sensitization in experimental animals (studies sorted by chain length; bold = HPV chemical)

Test substance	Species / Number of animals in study	Protocol and Test Conditions	Results	Reference
ALKYLSULFATES				
C_8 ASO_4 Na **CAS 142-31-4**	mouse 5 female CBA/J mice per group	LLNA Daily topical application of 12.5 µl of a 10, 50 or 100 % solution in dist. water on 4 consecutive days Positive controls: no data	not sensitizing (stimulation index: 1.25, 2.7 or 3.1)	Procter & Gamble Co. (1992b)
C_{12} ASO_4 Na **CAS 151-21-3**	mouse 4 female CBA/Ca mice per group	LLNA Daily topical application of 25 µl of a 5, 10 or 25 % solution in DMSO on 3 consecutive days Positive controls: no data	positive (stimulation index: 3.2, 4 or 4.2)	Basketter et al. (1994)
C_{12} ASO_4 Na **CAS 151-21-3**	mouse 4 female CBA/Ca mice per group	LLNA Daily topical application of 25 µl of a 4 (exp.1) or 5 (exp. 2), 10 (exp 1, exp 2) or 25 % (exp 1, exp 2) solution in DMF on 3 consecutive days Positive controls: no data	positive (stimulation indices: 4.1/4.0, 5.1/5.1 or 6.7/7.6)	Montelius et al. (1994)
C_{12} ASO_4 Na **CAS 151-21-3**	mouse 3 female BALB/c mice per group	LLNA a.) daily topical application of 25 µl of a 5, 10 or 25 % solution in water on 3 consecutive days b.) intradermal injection of 50 µl of a 0.05, 0.5 or 5 % solution in saline; after 5 days daily topical application of 25 µl of a 5 % solution in 50 % DMSO on 3 consecutive days Positive controls: no data	not sensitizing (stimulation indices: a.) 0.73, 1.61 and 1.13; b.) 1.58, 1.93 or 1.48)	Ikarashi et al. (1993)
C_{12-14} ASO_4 Na **CAS 85586-07-8**	guinea pig 10 animals	GPMT according to Magnusson and Kligman induction: intradermal injection with 0.08 % induction: covered patch application with 0.5 % challenge: covered patch application with 0.1 % Positive controls: no data	not sensitizing 0/10 guinea pigs reacted positive	Unilever Research (1977f)
C_{12-14} ASO_4 TEA **CAS 90583-18-9**	guinea pig 20 animals	GPMT according to Magnusson and Kligman induction: intradermal injection with 5 % induction: covered patch application with 5 % challenge: covered patch application with 1 % Positive controls: no data	not sensitizing During induction marked redness/swelling and in some cases necrosis of the skin was noted. The reapplication was tolerated without adverse effects both in treated animals and in controls	Henkel KGaA (1977a, 1999g)
C_{12-14} ASO_4 MEA CAS 90583-16-7	guinea pig 10 animals	OECD TG 406 (Buehler) induction: 4 % occlusive epicutaneous challenge: 2 % occlusive epicutaneous Positive controls: no data	not sensitizing After 24 hrs up to 30 % of the treated animals (up to 40 % in controls) showed weak dermal effects. 48 hrs later, 10 % of the treated animals as well as 10 % of controls showed weak dermal effects	Henkel KGaA (1993b)

Test substance	Species / Number of animals in study	Protocol and Test Conditions	Results	Reference
C_{12-14} ASO_4 Mg CAS 90583-23-6	guinea pig 20 animals	Freund's complete adjuvant test according to Directive 79/831/EEC, Annex V, Part B Induction: 0.1 % intracutaneous Induction: 2.5 % occlusive epicutaneous Challenge: 1 % occlusive epicutaneous Positive controls: no data	not sensitizing Slight skin edema in 2/20 animals 48 hrs after patch removal (no reaction in a re-challenge after 1 week with a 0.5 % aqueous solution of the TS) No mortality and slight body weight loss in treated animals	Henkel KGaA (1988b)
C_{12-15} ASO_4 Na **CAS 68890-70-0**	guinea pig 10 animals	GPMT Induction: 0.5 % injection Challenge: 0.5 % patch Positive controls: no data	not sensitizing (0/10 positive reactions)	Unilever Research (1975f)
C_{12-16} ASO_4 NH_4 **CAS 90583-12-3**	guinea pig 20 animals	GPMT according to Directive 79/831/EWG, Annex V, Part B induction: 0.1 % intracutaneous induction: 2.5 % occlusive epicutaneous challenge: 1 % occlusive epicutaneous Positive controls: no data	not sensitizing (none of the tested animals reacted positive) No mortality and no adverse effects on body weight gain	Henkel KGaA (1988a)
C_{12-18} ASO_4 Na **CAS 68955-19-1**	guinea pig 20 animals	OECD TG 406 (Buehler) induction: 12.5 % occlusive epicutaneous challenge: 6.25 % occlusive epicutaneous Positive controls: yes	not sensitizing After 24 hrs 4 treated animals showed slight skin reactions as well as 2 controls. After 48 hrs slight skin reactions were seen in 2 treated animals. Additionally in 1 treated and 1 control animal a slight skin reaction was seen in the test field treated with vehicle after 24 hrs	Henkel KGaA (1996c, 1996d)
C_{16-18} ASO_4 Na **CAS 68955-20-4**	guinea pig 20 animals	GPMT according to Directive 79/831/EWG, Annex V, Part B induction: 0.1 % intracutaneous induction: 10 % occlusive epicutaneous challenge: 5 % occlusive epicutaneous Positive controls: no data	not sensitizing Sensitization reaction: 1/20 animals showed a slight skin reaction in kind of a spotted redness 24 hrs after removing of the patches, which disappeared totally within 24 hrs. In controls no skin reactions were observed. Clinical signs: No mortality. Decreased body weight gain in treated animals as result of bandaging	Henkel KGaA (1986a, 1995)
ALKANE SULFONATES				
no data available				

Test substance	Species / Number of animals in study	Protocol and Test Conditions	Results	Reference
α -OLEFIN SULFONATES				
C_{14-16} =/OHASO$_3$ Na **CAS 68439-57-6**	guinea pig 12 – 15 animals per treatment group	GPMT in accordance with OECD TG 406 Positive controls: no data	not sensitizing (1/13 to 0/15 positive reactions)	Ter Haar (1983)
C_{14} =/OHASO$_3$ Na **CAS 93686-14-7**	guinea pig (male) 10 animals per treatment group	OECD TG 406 (GPMT) Induction: 0.1 % intracutaneous Induction: 18.12 % occlusive epicutaneous Challenge: 1 and 5 % occlusive epicutaneous Positive controls: yes	not sensitizing No reaction in negative controls and treated animals (readings after 24 and 48 hrs) at the maximum non-irritant concentration. No adverse clinical effects. The positive controls reacted as expected.	Lion Co. (2004b)
Mixture (1:1:1) of Sulfonic acids, C14-alkane hydroxyl and C14-alkene, magnesium salts (purity: 93.4 %) Sulfonic acids, C16-alkane hydroxyl and C16-alkene, magnesium salts (purity: 97.6 %) Sulfonic acids, C18-alkane hydroxyl and C18-alkene, magnesium salts (purity: 92.2 %) CAS 99999-99-9	guinea pig 15 animals	GPMT Induction: 0.5 % intracutaneous Induction: 2 % topical (no further information available) Challenge: 0.1 % topical (no further information available) Positive controls: no data	not sensitizing (0/15 animals reacted positive)	Lion Co. (1978c)

3.1.5 Repeated Dose Toxicity

Studies in Animals

Inhalation

Alkyl sulfates

There are no data available.

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

There are no valid data available.

Dermal

No data were available with regard to the repeated dose toxicity of alkane sulfonates and α-olefin sulfonates, and only limited information was available with regard to alkyl sulphates, as only one chemical of this category (C_{12-15} ASO_4 Na; CAS 68890-70-0) has been tested.

The individual results from these repeated dermal toxicity studies are summarized in Table 3-11.

Alkyl sulphates

Data were available for only one chemical of this category, the alkyl sulfate C_{12-15} ASO_4 Na (CAS 68890-70-0), which was tested in two studies on mice (Unilever Research, 1976c, Unilever Research, 1977c). These studies were conducted before the implementation of the OECD TG 410 (1981). It is recognized that the mouse is not the recommended species of OECD TG 410, nevertheless these studies give important information on the toxicological profile of alkyl sulfates.

The first study was performed to examine the effects on mouse skin and to make a preliminary assessment of concentrations suitable for use in a 90-day dermal study. In this 3-week study (Unilever Research, 1976c), groups of 3 mice per sex and dose were treated with 0.2 ml of a 0, 5, 10, 15 or 18 % aqueous solution twice weekly (corresponding to ca. 0, 200, 400, 600 or 720 mg/kg bw/day, based on an average weight of 20g / mouse and a 5 days / week treatment). At the end of the trials, hematological investigations were undertaken and organ weights analysed for significant effects. Detailed macroscopic and histological examination of the mice was also made. The 18 % solution induced epidermal necrosis and ulceration of such severity that the mice died or were killed for humanitarian grounds. No deaths occurred in the groups treated with 5 - 10% solutions and the general health of these animals remained good. Mice treated with a 15% solution had an increased water intake. The relative liver weights of males and the relative kidney and heart weights of females of this group were increased. Both macroscopic and histological lesions at the site of application were found (ulceration in 3 animals; in all acanthosis, hyperkeratosis and hypergranulosis). The application of 10% solutions resulted in a hyperplastic response of the skin, with no cytotoxic effects. No significant systemic effects were recorded in mice treated with 10 % solution (corresponding to a NOAEL of 400 mg/kg bw/day).

In the 13 week study, groups of 10 mice per sex and dose were treated with 0.2 ml of a 0, 5, 10, 12.5 or 15 % aqueous solution of C_{12-15} ASO_4 Na twice weekly (Unilever, 1977c). Based on an average weight of 20g / mouse and a 5 days / week treatment, the applied doses corresponds to

about 0, 200, 400, 500 and 600 mg/kg bw/day. Observations were made on general health, water intakes and survival. At the end of the trial, hematological investigations were undertaken and organ weights were analysed for significant effects. Detailed macroscopic and microscopic examinations of tissues from the mice were also made. Apart from one death in the 12.5% treatment group due to anorexia and dehydration, the health of the mice remained good throughout the trial. Systemic effects such as changes in organ weights (liver, kidney and heart weights) were seen at ≥ 12.5 %. The increased water intake at ≥ 10 % may reflect accelerated loss of water through the altered epidermis. The enlargement of the liver is probably an indication of increased protein synthesis to offset loss of plasma protein (exudate). At concentrations of 12.5 and 15%, cytotoxic effects were found in the epidermis. The application of the 10 % solution did not produce any significant effect (corresponding to a NOAEL of 400 mg/kg bw/day).

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

There are no data available.

Oral

The individual results from reliable repeated oral dose toxicity studies are summarized in Table 3-12.

Alkyl sulfates

Reliable studies have been conducted with C_{12} ASO_4 Na (CAS 151-21-3), C_{12-14} ASO_4 TEA (CAS 90583-18-9), C_{12-15} ASO_4 Na (CAS 68890-70-0), C_{16-18} ASO_4 Na (CAS 68955-20-4) and C_{13-15} ASO_4 Na (CAS 86014-79-1). Hence, alkyl sulfates with chain lengths between C_{12} and C_{18} have been tested.

C_{12} ASO_4 Na was tested in a 90-day feeding study on rats (Walker et al., 1967). Twelve male and 12 female rats/group were fed dietary levels of 40, 200, 1000 or 5000 ppm (corresponding to 3, 17, 86 or 430 mg/kg bw/day). The control group (18 males, 18 females) received the diet alone. Daily observations were made on health. Body weight and food intake were recorded weekly. Urine samples were obtained from the 5000 ppm and control groups during week 12. The urine was examined for color, pH, protein, reducing substances, bile salts and microscopic constituents. Terminal blood samples were taken by cardiac puncture and erythrocyte and leucocyte counts and determinations of hematocrit and hemoglobin were made. Total plasma protein and urea were determined. Gross pathological and histological examination of a wide range of organs were made. The only effects observed occurred at 5000 ppm and comprised increases in liver weights in female animals. The NOAEL was at 1000 ppm (= 86 mg/kg bw/day).

A similar NOAEL (90 mg active substance/kg bw/day) was obtained when a 90 % aqueous solution of C_{12} ASO_4 Na was administered for 28 days by gavage to groups of 5 animals/sex/dose at dose levels of 30, 100 or 300/600 mg/kg bw/day (the dose of 300 mg/kg bw/day was changed into 600 mg/kg bw/day after 10 days of treatment) in a study performed in accordance with OECD TG 407 except for the functional observation battery (Henkel KGaA, 1987h). At the LOAEL (270-540 mg active substance/kg bw/day), feed intake and body weight gain were reduced, and water intake increased. Bleeding and ulceration of the stomach, as well as transient alterations of the tongue and myocard were found. There was an increase in leucocytes and in alanine aminotransferase (ALT) activity, as well as a decrease in hematocrit and erythrocyte volume

(MCV). Relative weights of adrenals, kidneys, brain, gonads and liver were increased; the relative thymus weight was decreased.

With the same study design (which meets all requirements of the OECD TG 407 except for functional observation battery tests), C_{12-14} ASO_4 TEA was administered by gavage as a ca. 40% aqueous solution at dose levels of 0, 70, 250 or 750 mg/kg bw/day (corresponding to 0, 29, 102 and 306 mg active substance/kg bw/day) to groups of 5 rats/sex/dose (Henkel KGaA, 1988e). At 250 mg/kg bw/day (i.e. 102 mg active substance/kg bw/day), signs of local irritation were found in the forestomach (inflammation, ulceration in some animals), but no indication of a systemic toxicity. Therefore, this level is considered as the systemic NOAEL. At 750 mg/kg bw/day (i.e. 306 mg active substance/kg bw/day), the severity of gastric irritation increased, and the animals showed leucocytosis (LOAEL).

C_{12-15} ASO_4 Na was investigated in a 3-week, a 13-week, and in two 2-year studies with rats, all using the dietary route of exposure (Unilever Research 1975e, 1976d, 1995a,b). In the 3-wk study, 3 animals/sex/dose were fed 0, 0.047, 0.094, 0.188, 0.375, 0.75 or 1.5 % in diet (corresponding to 0, 62, 117, 252, 503, 1010, or 1956 mg/kg bw/day; Unilever Research 1975e). The study included clinical observations, food and water intake measurements, determination of body and organ weights, and macroscopic and microscopic evaluations. No effects were found up to a dose level of 252 mg/kg bw/day (NOAEL). The LOAEL was at 503 mg/kg bw/day (reduced body weight, liver parenchymal hypertrophy). When tested at dietary concentrations of 0, 0, 0.07, 0.14, 0.28, 0.56, 1.13 or 2.25 % in groups of 10 rats/sex/dose in a study that meets current standards (except for neurotoxicity and immunotoxicity testing; Unilever Research 1976d), the NOAEL was at 0.14% (=122 mg/kg bw/day). At the LOAEL of 0.28% (= 245 mg/kg bw/day, hypertrophy of the liver was found in the microscopic examination. Liver weights were increased only at 488 mg/kg bw/day. In two comprehensive 2-year studies with groups of 45 animals/sex/group (Unilever Research 1995a,b), a similar NOAEL of 113 mg/kg bw/day was found. The LOAELs were in both studies at 1125 mg/kg bw/day with a clear indication of the liver as target organ (liver weights and liver enzymes increased, histopathological changes in the liver). There was no indication of another target organ in these very comprehensive studies. No adverse effects were found with regard to the kidneys (reduced incidence of nephrocalcinosis, reduced incidence of chronic nephropathy).

C_{16-18} ASO_4Na was tested in two dietary studies (for 3 and 13 weeks), and in a gavage study (for 13 weeks) (Unilever Research, 1976e, 1977d, Henkel KGaA, 1987f, 1995). In the 3-week study, groups of 3 rat/sex/dose were fed with diets containing 0, 0.047, 0.094, 0.188, 0.375, 0.75 or 1.5 % (corresponding to 0, 50, 103, 202, 417, 796, and 1660 mg/kg bw/day; Unilever Research 1976e). No effects were found at 202 mg/kg bw/day (NOAEL). At the LOAEL of 417 mg/kg bw/day, liver hypertrophy and modest changes in clinical chemistry were reported. Liver weights were only increased at a dose of 1660 mg/kg bw/day. There were no adverse effects on the kidney up to the highest dose tested. In the 13-week study (Unilever Research, 1977d), 10 animals/sex/group were fed diets containing 0, 0.07, 0.14, 0.28, 0.56, 1.13 or 2.25 % (corresponding to 0, 61, 123, 230, 482, 970, or 2067 mg/kg bw/day), the NOAEL was established at 123 mg/kg bw/day. At the LOAEL (230 mg/kg bw/day), elevated liver weights in females, and hypertrophy of the liver, also in females, was observed. In males, the same effects on the liver were seen at the next higher dose of 482 mg/kg bw/day. A reduced relative kidney weight was found at 970 mg/kg bw/day, but at the top dose level the kidney weight was increased and the incidence or severity of nephrocalcinosis was reduced. In the gavage study, C_{16-18} ASO_4Na was administered as 55% aqueous solution to groups of 10 rats/sex/dose at dose levels of 100, 300 and 900 mg/kg bw/day, corresponding to ca. 55, 165 and 495 mg active substance/kg bw/day, in a 13-week study in compliance with current standards (Henkel KGaA, 1987f, 1995). The NOAEL was established at 55 mg active substance/kg bw/day. At the next higher dose level (165 mg active substance/kg bw/day) food consumption and

body weight gain were reduced, and relative liver weight was increased. Other changes were non-specific and probably due to the irritant effect of the test substance to the stomach mucosa.. At 495 mg/kg bw/day, there were clear signs of gastritis; absolute and relative liver weights were increased. No signs of toxicity were found in the kidney.

$C_{13\text{-}15}$ ASO_4 Na shows an identical profile with similar NOAELs and LOAELs (see Table 3-13).

In summary, gastrointestinal irritation was the primary effect after application via gavage but not after application via the diet. This is consistent with the primary irritant properties of the alkyl sulfates and the bolus effect after application by gavage. After administration in the diet, the liver was the only target organ identified. Adverse effects on this organ included an increase in liver weight, enlargement of liver cells, and elevated levels of liver enzymes. The lowest effect level for liver toxicity was 230 mg/kg bw/day in a 13 feeding week study with $C_{16\text{-}18}$ ASO_4 Na. The lowest NOAEL was 55 mg active substance/kg bw/day in a 13 week gavage study with $C_{16\text{-}18}$ ASO_4 Na. In most studies a decrease in weight gain was found, which was accompanied at higher concentrations by reduced food intake. The abdominal fat was reduced considerably at these dose levels.

Table 3-13: NOAELs and LOAELs (as active substance) for repeated dose toxicity studies of alkyl sulfates in rats

Substance	Duration (weeks)	Route	NOAEL (mg/kg bw/day)	LOAEL (mg/kg bw/day)	Reference
C_{12} ASO_4 Na	4	gavage	90	270 - 540	Henkel KGaA (1987h)
C_{12} ASO_4 Na	13	diet	86	430	Walker et al. (1967)
$C_{12\text{-}14}$ ASO_4 TEA	4	gavage	102	306	Henkel KGaA (1988e)
$C_{12\text{-}15}$ ASO_4 Na	3	diet	252	503	Unilever Research (1975e)
$C_{12\text{-}15}$ ASO_4 Na	13	diet	122	245	Unilever Research (1976d)
$C_{12\text{-}15}$ ASO_4 Na	104	diet	113	1125	Unilever Research (1995a, 1995b)
$C_{13\text{-}15}$ ASO_4 Na	3	diet	199	384	Unilever Research (1976f)
$C_{13\text{-}15}$ ASO_4 Na	13	diet	134	253	Unilever Research (1977e)
$C_{16\text{-}18}$ ASO_4 Na	13	diet	123	230	Unilever Research (1977d)
$C_{16\text{-}18}$ ASO_4 Na	13	gavage	55	165	Henkel KGaA (1987f, 1995)
$C_{16\text{-}18}$ ASO_4 Na	3	diet	202	417	Unilever Research (1976e)

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

In a comprehensive two-year feeding study, groups of 50 males and 50 female CFY rats were dosed with 0, 1000, 2500 or 5000 ppm of $C_{14\text{-}16}$ =/$OHASO_3$ Na in the diet (corresponding to 0, 39-57, 96-132 and 195-259 mg /kg bw/day). Apart from a slight reduction in food intake (in females only) and a significant reduction in body weight gain (in both sexes) between weeks 14 and 26 of the study of the animals in the high-dose group, no adverse effects were reported. Blood chemistry,

urinalyses and histopathological findings were all comparable to control values (Lion Co., 1975; Hunter & Benson, 1976). Based on the results from this study a NOAEL of 96-132 mg/kg bw/day can be derived.

In another study rats were dosed by gavage with 0, 100, 250 or 500 mg/kg bw/day of C_{14} =/$OHASO_3$ Na for 6 months. At the highest dose level of 500 mg/kg bw/day the mortality was increased, food consumption was slightly decreased in males and females, GOT, GPT and ALP values and adrenal weights were increased. The body weight gain was decreased in animals of both sexes at 250 mg/kg bw/day (Kitasato University, 1968). No adverse effects were reported at a dose level of 100 mg/kg bw/day.

Conclusion

For repeated dermal application a "No Observed Adverse Effect Level" (NOAEL) of 400 mg/kg bw/day was found in mice treated twice weekly for 3 or 13 weeks with 0.2 ml of C_{12-15} ASO_4 Na at concentrations of 0, 5, 10, 12.5 or 15% in water (corresponding to ca. 0, 200, 400, 500, or 600 mg/kg bw/day). At 10 % concentration, epidermal hyperplasia, and at concentrations of≥ 12.5 % in addition epidermal cytotoxicity (ulceration) as well as changes in organ weights was found.

After repeated oral application of alkyl sulfates with chain lengths between C_{12} and C_{18}, the liver was the only target organ for systemic toxicity. Adverse effects on this organ included an increase in liver weight, enlargement of liver cells, and elevated levels of liver enzymes. The lowest observed adverse effect level (LOAEL) for liver toxicity (parenchymal hypertrophy and increase in relative liver weight) was found for C_{16-18} ASO_4 Na in a 13-week dietary study on rats at 230 mg/kg bw/day. The lowest NOAEL was 55 mg active substance/kg bw/day in a 13 week gavage study with C_{16-18} ASO_4 Na.

NOAELs of about 100 mg/kg bw/day were found for rats in comprehensive oral 6 month- and 2-year studies with C_{14}– and C_{14-16}- α-olefin sulfonates. At 200-250 mg/kg bw/day, a reduction in body weight gain was the only adverse effect in these studies.

No data were available with regard to the repeated dose toxicity of alkane sulfonates. Based on the similarity of metabolic pathways between alkane sulfonates, alkyl sulfates and α-olefin sulfonates, the repeated dose toxicity of alkane sulfonates is expected to be similar with NOAEL and LOAEL values in the same range as for alkyl sulfates and α-olefin sulfonates, i.e. 50 - 100 and 200-250 mg/kg bw/day, respectively, with the liver as potential target organ.

Table 3-11: Studies on repeated dose toxicity after dermal application (bold = HPV chemical)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	NOAEL	LOAEL	Results	Reference
ALKYLSULFATES							
C_{12-15} ASO_4 Na CAS 68890-70-0	mouse C57B1 3 males and females per dose group	treatment twice weekly with 3 day intervals for a total of 3 weeks	0.2 ml of a 0, 5, 10, 15 or 18 % aqueous solution perr application (ca. 0, 200, 400, 600 or 720 mg/kg bw/day)	10 % (ca, 400 mg/kg bw/day)	15 % (ca, 600 mg/kg bw/day)	5%: no observed adverse effect 10 %: skin edema ↑, hyperkeratosis ↑, hypergranulosis ↑, acanthosis ↑; 15 %: water consumption ↑ epidermal hyperplasia, mild epidermal cytotoxicity, rel liver weight (m) ↑, rel kidney and heart weights (f) ↑ 18 %: all mice died or were killed due to dehydration and poor condition (loss of fluid through the ulcerated skin); epidermal necrosis and ulceration;	Unilever Research (1976c)
C_{12-15} ASO_4 Na CAS 68890-70-0	mouse C57B1 10 males and females per dose group	twice weekly with 3 day intervals for a total of 13 weeks	0.2 ml of a .: 0, 5, 10, 12.5 or 15 % aqueous solution per application (ca. 0, 200, 400, 500, or 600 mg/kg bw/day)	10 % (ca. 400 mg/kg bw)	12.5 % (ca. 500 mg/kg bw)	5%: no observed adverse effect ≥ 10 %: water intake (m/f) ↑ ≥ 12.5 %: one mouse died after 1 week (dehydration, anorexia; extensive necrosis and ulceration of the skin, ulceration of the tip of the tongue and total depletion of hepatic glycogen accompanied by a considerable reduction in parenchymal cytoplasmic basophilia); cytotoxic effects in epidermis; relative liver weights (f) ↑ 15%: hemoglobin (m) ↓, heart weight (f) ↑, rel. kidney weight (f) ↑, rel liver weight (m) ↑, testes weight not affected	Unilever Research (1977c)
ALKANE SULFONATES							
no data available							
α-OLEFIN SULFONATES							
no data available							

Table 3-12: Studies on repeated dose toxicity after oral application (substances sorted by chain length; bold = HPV chemical)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
ALKYLSULFATES							
C_{12} ASO_4 Na a.i.: > 90 % CAS 151-21-3	rat Sprague-Dawley; 10 males and females per dose group; satellite groups for recovery (0 or 300 / 600 mg/kg bw/day): 5 males and females for 29 days p.a.	4 weeks	Directive 79/831/EEC, Annex V, Part B gavage 0, 30, 100, or 300 / 600 mg/kg bw/day (high dose was changed from 300 to 600 mg/kg bw/day after 10 treatments)	ca. 90	ca. 270 - 540	100 mg/kg: no effects 300 - 600 mg/kg: feed intake and weight gain (m) ↓; water intake ↑; haematocrit and MCV ↓; number of leucocytes and neutrophile leucocytes ↑; ALT ↑; relative weights of adrenals, kidney, brain, gonads and liver ↑; relative thymus weight ↓; ulcerations and bleedings in the stomach; alterations of the tongue and myocard (fully reversible within 29 days p.a.) and forestomach (partially reversible within 29 days p.a.)	Henkel KGaA (1987h)
C_{12} ASO_4 Na a.i.: 86 % CAS 151-21-3	rat Carworth Farm 'E'; 12 males and females per dose group; 18 male and females as controls	13 weeks	0, 40, 200, 1000 or 5000 ppm in diet (corresponding to 0, 3, 17, 86, 430 mg/kg bw/day)	ca. 86	ca. 430	0, 40, 200, 1000 ppm: no adverse effects on health, behaviour, body weight, food intake, or hematology and serum chemistry 5000 ppm: absolute liver weights (f) ↑, no pathological findings at necropsy and in histology, no adverse findings in urinalysis.	Walker et al. (1967)
C_{12-14} ASO_4 TEA a.i.: 40.9 – 42 % CAS 90583-18-9	rat CD 10 males and females per dose group; satellite groups for recovery (0 or 750 mg/kg bw): 5 males and females over 28 days p.a.	4 weeks	Directive 79/831/EEC, Annex V, Part B gavage 0, 70, 250 or 750 mg/kg bw	102	306	70 mg/kg: no effects 250 mg/kg: Hb values (f) ↑; forestomach: individual inflammation and edema/ulcerations; no indication of systemic toxicity 750 mg/kg: leukocytes (f) ↑; forestomach: inflammation, edema, ulceration, acanthosis and papillomatous hyperplasia (these alterations were reversible; data from satellite group)	Henkel KGaA (1988e)
C_{12-15} ASO_4 Na CAS 68890-70-0	Rat Wistar 3 males and females per dose group (6 males and females as controls)	3 weeks	0, 0.047, 0.094, 0.188, 0.375, 0.75 or 1.5 % in diet (corresp. to m: 0, 63, 118, 253, 490, 1002 or 2008 mg/kg bw/day; f: 0, 61, 115, 250, 516, 1017 or 1904 mg/kg bw/day)	252	503	252 mg/kg: no effect ≥ 503 mg/kg: body weight gain (m) ↓; terminal body weights (m) ↓; relative brain weights (m) ↑; liver: parenchymal hypertrophy ↑ ≥ 1010 mg/kg: ALT (m) ↑; liver: diffuse parenchymal hypertrophy; relative liver weights (f) ↑; kidney: absolute weights (m) ↓ 1956 mg/kg: food/water intake (m) ↓; food utilization (m) ↓; GPT (f) ↑; relative liver weights (m) ↑ adrenal weights (m) ↓; relative testes weights ↑	Unilever Research (1975e)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
$C_{12\text{-}15}$ ASO_4 Na CAS 68890-70-0	rat Wistar 10 males and females per dose group (20 males and females as controls)	13 weeks	0, 0.07, 0.14, 0.28, 0.56, 1.13 or 2.25 % in diet (=m: 0, 58, 113, 228, 470, 961 or 1944 mg/kg bw/day; f: 0, 66, 131, 261, 506, 1070 or 2218 mg/kg bw/day)	122	245	122 mg/kg: no effect 245 mg/kg: liver: periportal parenchymal hypertrophy (f) ≥ 488 mg/kg: relative liver weights (m/f) ↑; cytoplasmic (glycogenic) vacuolation ↓; cytoplasmic neutral fat / hemosiderin content ↓; liver: periportal parenchymal hypertrophy (m) ≥ 1016 mg/kg: body weight gain (m) ↓; serum GPT (m/f) ↑; serum AP (m/f) ↑; absolute spleen weights (m) ↑; relative kidney weights (f) ↑; relative testes weights ↑; absolute liver weights (f) ↑ 2081 mg/kg: body weight gain (f) ↓; feed intake (m/f) ↓; water intake (f) ↓; serum protein (m) ↓; serum Mg, protein, cholesterol (m) ↓; serum GOT (m) ↑; absolute spleen weights (f) ↑; absolute kidney weights (m) ↓; virtually no abdominal fat / changes in colour and consistency of intestinal contents (m; findings less frequently in f); liver: diffuse hypertrophy (m/f); incidence/severity of nephrocalcinosis (f) ↓; lymphatic dilation of small intestine (m/f)	Unilever Research (1976d)
$C_{12\text{-}15}$ ASO_4 Na CAS 68890-70-0	rat Wistar 45 males and females per dose group	104 weeks	0, 0.015, 0.15 or 1.5 % in diet (ca. 0, 11, 113 or 1125 mg/kg bw/day)	ca. 113	ca. 1125	ca. 113 mg/kg: no effect ca. 1125 mg/kg: food/water intake and growth rate (m/f) ↓; SGOT, ALT, LDH and ALP values (m) ↑; liver: absolute/ relative weights ↑; zonal/diffuse parenchymal hypertrophy (m/f) ↑; pigmented lipid granulomata (f) ↑; focal coagulative/ hemorrhage necrosis (m) ↑; extramedullary erythopoiesis (m/f) ↓; kidneys: severity and/or incidence of chronic nephropathy, pelvic nephrocalcinosis and pelvic epithelial hyperplasia (m/f) ↓; heart: severity and/or incidence of arterial medial hypertrophy and patchy myocardial fibrosis (m/f) ↓; spleen: hemosiderin deposition (m) ↑; myelopoiesis (m/f) ↓; stem cell hyperplasia (m) ↓; brain: relative weights ↑; testes: relative weights ↑; severity and/or incidence of focal/ multifocal arteritis ↓	Unilever Research (1995a)
$C_{12\text{-}15}$ ASO_4 Na CAS 68890-70-0	rat Wistar 45 males and females per dose group	104 weeks	0, 0.015, 0.15 or 1.5 % in diet (ca. 0, 11, 113 or 1125 mg/kg bw/day)	ca. 113	ca. 1125	ca- 113 mg/kg: no effect ca. 1125 mg/kg: food/water intake and growth rate (m/f) ↓; total white cell count (f) ↓; ALT and ALP values (m) ↑; LDH and HDB values (f) ↓; liver: absolute/relative weights (m/f) ↑; zonal/diffuse parenchymal hypertrophy (m/f) ↑; pigmented lipid granulomata (f) ↑; focal coagulative/hemorrhage necrosis (m) ↑; spleen: relative weights (m) ↓; erythropoiesis, hemosiderin deposition, myelopoiesis and stem cell hyperplasia (f) ↓; red pulp hemosiderin (f) ↑; heart: relative weights (m) ↓; severity and/or incidence of arterial medial hypertrophy ↓; kidneys: relative weights (m) ↓; severity and/or incidence of chronic nephropathy and pelvic nephrocalcinosis ↓; adrenals: relative weights (m) ↓; testes: relative weights ↑	Unilever Research (1995b)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
$C_{13\text{-}15}$ ASO_4 Na CAS 86014-79-1	rat Wistar 3 males and females per dose group (6 males and females as controls)	3 weeks	0, 0.047, 0.094, 0.188, 0.375, 0.75 or 1.5 % in diet (ca. m: 0, 49, 98, 203, 378, 757 or 1486 mg/kg bw/day; f: 0, 52, 96, 195, 390, 812 or 1645 mg/kg bw/day)	199	384	199 mg/kg: no effect ≥ 384 mg/kg: liver: periportal parenchymal hypertrophy (m/f); cytoplasmic (glycogenic) vacuolization / cytoplasmic neutral fat content (m/f) ↓ ≥ 785 mg/kg: LDH (m/f) ↑; total serum protein (m) ↓; relative liver weights (m/f) ↑; diffuse parenchymal hypertrophy (f) 1566 mg/kg: body weight gain (m/f) ↓; food/water intake and terminal body weights (f) ↓; relative kidney and brain weights (f) ↑; absolute spleen weights (f) ↓; serum calcium levels (m/f) ↓; GOT, GPT, LDH and HBDH (m/f) ↑; ALP (m) ↓; CPK (m) ↑	Unilever Research (1976f)
$C_{13\text{-}15}$ ASO_4 Na CAS 86014-79-1	rat Wistar 10 males and females per dose group (20 males and females as controls)	13 weeks	0, 0.07, 0.14, 0.28, 0.56, 1.13 or 2.25 % in diet (ca- m: 0, 60, 115, 236, 464, 921 or 1924 mg/kg bw/day; f: 0, 68, 152, 269, 559, 1092 or 2268 mg/kg bw/day)	134	253	134 mg/kg: no effect ≥ 253 mg/kg: one f died (vaginal hemorrhage/ anemia); terminal weights (m) ↓; serum AP (f) ↑; absolute/relative liver weights (f) ↑; absolute spleen weights (m) ↑; absolute kidney weights (m) ↓; liver: periportal parenchymal hypertrophy (f) ≥ 512 mg/kg: serum cholesterol (f) ↓; serum AP (m) ↑; changes in colour and consistency of intestinal contents (m/f); virtually no abdominal fat (f); liver: periportal parenchymal hypertrophy (m) ≥ 1007 mg/kg: feed intake (m/f) ↓; weight gain (m) ↓; serum cholesterol (m) ↓; serum triglycerides (m) ↓; serum GPT (m) ↑; serum cholinesterase (m) ↑; relative liver weights (m) ↑; absolute spleen weights (f) ↑; relative brain weights (m) ↑; relative testes weights ↑; liver: diffuse parenchymal hypertrophy (m/f) 2096 mg/kg : water intake (m/f) ↓; weight gain (f) ↓; terminal weights (f) ↓; serum glucose (f) ↓; serum GOT (m) ↑; serum GPT (f) ↑; relative kidney weights (f) ↑; relative brain weights (f) ↑; virtually no abdominal fat (m); nephrocalcinosis (f) ↓; lymphatic dilation of the intestine (m/f) ↑	Unilever Research (1977e)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
C_{16-18} ASO_4 Na CAS 68955-20-4	rat Wistar 3 males and females per dose group (6 males and females as controls)	3 weeks	0, 0.047, 0.094, 0.188, 0.375, 0.75 or 1.5 % in diet (ca. m: 0, 49, 101, 197, 410, 798 or 1634 mg/kg bw/day; f: 0, 51, 105, 206, 424, 794 or 1685 mg/kg bw/day	202	417	202 mg/kg: no effect ≥ 417 mg/kg: changes in clinical chemistry (GPT (m/f) ↑, LDH (m) ↑, ALP (m) ↓; CPK (m/f) ↑); relative adrenal weights (f) ↓; liver: parenchymal hypertrophy (m/f) ↑ ≥ 796 mg/kg: water intake (m) ↓; terminal body weights (m) ↓; ; absolute kidney weights (m) ↓; body fat depots (m/f) ↓ 1660 mg/kg: body weight gain (m/f) ↓; food utilization (m) ↓; food intake (f) ↓; water intake (f) ↓; size (m) ↓; absolute heart weights (m/f) ↓; relative liver weights (m/f) ↑; relative brain weights (m) ↑; absolute spleen weights (m) ↓; absolute adrenal weights (m/f) ↓; relative adrenal weights (f) ↓; relative testes weights ↑; ileum: contents bulky and mucoid (m/f); liver: neutral fat content of parenchymal cells (m/f) ↑; kidneys: intensity of renal lesions ↓; spleen: hemopoietic activity ↓; uterus: no ovarian activity or endometrial stimulation and only minimal endometrial hyperplasia	Unilever Research (1976e)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
C_{16-18} ASO_4 Na CAS 68955-20-4	rat Wistar 10 males and females per dose group (20 males and females as controls)	13 weeks	0, 0.07, 0.14, 0.28, 0.56, 1.13 or 2.25 % in diet (cam: 0, 54, 106, 216, 432, 924 or 1890 mg/kg bw/day; f: 0, 68, 140, 243, 531, 1016 or 2244 mg/kg bw/day)	123	230	123 mg/kg: No effect ≥ 230 mg/kg: food intake (f) ↓; relative liver weights (f) ↑; liver: parenchymal hypertrophy (f) ↑ ≥ 482 mg/kg: body weight gain (f) ↓; terminal body weights (f) ↓; PCV / hemoglobin levels (m) ↓; absolute liver weights (f) ↑; relative liver weights (m) ↑; relative brain weights (f) ↑; liver: parenchymal hypertrophy (m) ↑; small intestine: changes in colour, consistency and volume of the contents (m/f) ≥ 970 mg/kg: 1 male died (herniation of the stomach); body weight gain (m) ↓; water intake (m/f) ↓; terminal body weights (m) ↓; absolute heart weights (m/f) ↓; relative testes weights ↑; absolute spleen weights (m/f) ↓; absolute kidney weights (m/f) ↓; relative brain weights (m) ↑; liver: glycogenic vacuolation, cytoplasmic basophilia, neutral fat content and hemosiderin content of parenchymal and Kupffer cells (m/f) ↓ 2067 mg/kg: food intake (m) ↓; relative heart weights (m) ↑; absolute pituitary weights (m) ↓; relative kidney weights (m/f) ↑; absolute adrenal weights (m) ↓; absolute liver weights (m) ↓; relative liver weights (m/f) ↑; absolute brain weights (m/f) ↓; loss of abdominal fat depots (m/f); kidneys: incidence and/or severity of nephrocalcinosis (f) ↓; lymphatic dilation of the intestine (m/f) ↑	Unilever Research (1977d)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
C_{16-18} ASO_4 Na a.i.: 55 % CAS 68955-20-4	rat Sprague-Dawley 10 males and females per dose group; satellite groups for recovery (0 or 900 mg/kg bw): 5 males and females over 33 days p.a.	13 weeks	Directive 79/831/EEC, Annex V, Part B gavage 0, 100, 300 or 900 mg/kg bw	55	165	100 mg/kg: no effect ≥ 300 mg/kg bw: food consumption (m/f) ↓; body weight gains (m) ↓; hemoglobin concentrations (f) ↑; thrombocytes (f) ↑; changes in clinical chemistry (serum GPT / GOT / creatinine; alkaline phosphatase; blood glucose; proteins) (m/f); neutrophils (m) ↑; lymphocytes (m) ↓; relative brain weights (m) ↑; absolute heart weights (m) ↓; relative liver weights (m) ↑; forestomach: slight acanthosis / hyperkeratosis (m) 900 mg/kg bw: body weight gains (f) ↓; haematocrit values and hemoglobin concentrations (m/f) ↑; WBC (m/f) ↑; thrombocytes (m) ↑; neutrophils (m/f) ↑; lymphocytes (m/f) ↓; absolute/relative thymus weights (f) ↓; absolute/relative spleen weights (m) ↑; relative adrenal weights (f) ↑; absolute kidney weights (f) ↓; absolute liver weights (f) ↑; relative liver weights (m/f) ↑; forestomach: inflammation / proliferative changes (epithelial hyperplasia, inflammatory cell infiltrates with and without edema, ulcers) (m/f); thymus: slight to moderate degree of diffuse atrophy (especially in f); liver, spleen and kidneys: slight discoloration without remarkable histopathological findings (m/f) Satellite group: no significant effects on liver, thymus or spleen and partial regeneration of the forestomach	Henkel KGaA (1987f; 1995)
ALKANE SULFONATES							
no data available							

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Protocol Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
α -OLEFIN SULFONATES							
C_{14-16} =/$OHASO_3$ Na mixture of alkenyl sulfonate and hydroxyalkane sulfonate (60.4:39.6 % w/w) a.i.: 97.93 % CAS 68439-57-6	rat Sprague-Dawley CFY 50 males and females per dose group	104 weeks	oral feed via diet 0, 1000, 2500, or 5000 ppm (m: 0, 39, 96, or 195 mg/kg bw/day; f: 0, 57, 132, or 259 mg/kg bw/day)	96-132	195-259	Mortality after 104 weeks (m/f): 0 ppm: 22 / 25 1000 ppm: 23 / 19 2500 ppm: 27 / 27 5000 ppm: 20 / 20 < 5000 ppm: no adverse clinical, haematological or clinical chemistry effects; no adverse histopathological findings (complete necropsy on all surviving rats) 5000 ppm: body weight gain: slight depression between weeks 14 - 26 of treatment in males (108, 112, 107 or 91 g [$p < 0.05$]) and females (64, 55, 59 or 46 g [$p < 0.001$]); food/water consumption: minor depression of food intake in females during the first year of treatment: week 1 - 13: 96 % of control value ($p < 0.01$); week 14 - 26: 93 % of control value ($p < 0.01$); week 27 - 52: 94 % of control value ($p < 0.05$)	Lion Co. (1975); Hunter & Benson (1976)
C_{14} =/$OHASO_3$ Na a.i.: not further specified CAS 93686-14-7	rat Wistar 10 males and females per dose group	26 weeks	gavage 0, 100, 250 or 500 mg/kg bw/day	250		≥ 250 mg/kg: body weight gain ↓ (final weights in males: 395, 395, 367 or 343 g; final weights in females: 328, 321, 307 or 289 g) 500 mg/kg: mortality ↑ (3 males on days 84, 96 or 115; 3 females on days 66, 85 or 132); transitional softening stools with slight occult blood in a few males and females; food consumption slightly decrease in males and females; GOT, GPT and ALP ↑; urea nitrogen, serum albumin and total protein ↓; adrenal weights ↑; slight hemorrhages in kidneys and spleen (sex or number of animals not reported)	Kitasato University (1968)

3.1.6 Mutagenicity

In vitro Studies

The individual results of the available and reliable *in vitro* tests are summarized in Table 3-14.

Alkyl sulfates

Various mutagenicity studies in bacteria and mammalian cells are available which were performed according to current standards (OECD TG 471 and 476) and for which sensitivity has been proven through positive controls that showed the expected effects.

Alkyl sulfates of different chain lengths and with different counter ions (Na, NH4, Mg, MEA and TEA) were not mutagenic in the Ames test (according to OECD TG 471) with and without metabolic activation, and tested up to and including cytotoxic concentrations.

C_{12} ASO_4 Na, C_{14} ASO_4 Na and C_{16} ASO_4 Na were not genotoxic in mammalian cell cultures with and without metabolic activation and tested up to and including cytotoxic concentrations (Mouse lymphoma assays, performed in accordance with OECD TG 476) (Procter & Gamble Co., 1981; McGregor et al., 1988).

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

C_{14} amd C_{14-16} -α-olefin sulfonates were tested negative in the Ames test both in the presence and absence of metabolic activation up to concentrations that induced clear cytotoxicity (with *Salmonella typhimurium* and *Escherichia coli* WP2uvrA according to OECD TG 471). They did not induce chromosome aberrations in V79 cells or CHL cells. All tests were performed with and without metabolic activation according to OECD TG 473 (Hoechst AG, 1988a, 1989; Kao Co., 1996; Lion Co., 2004a).

In vivo Studies

The individual results of the *in vivo* tests are summarized in Table 3-15.

Alkyl sulfates

Alkyl sulfates of different chain lengths and with different counter ions (Na and TEA) were tested by oral dosing in the diet or by gavage in a chromosome aberration assay in rats and hamsters, a dominant lethal assay in mice and in micronucleus assays in mice (Unilever Research, 1976a, 1976h, 1976m, 1977b; Hope, 1977; Henkel KGaA, 1986b, 1987k). The alkyl sulfates did not induce chromosome aberrations in two micronucleus assays (C_{12-14} ASO_4 TEA and C_{16-18} ASO_4 Na), in the chromosome aberration assays (C_{12} ASO_4 Na and C_{12-15} ASO_4 Na), and in the dominant lethal assays (C_{12} ASO_4 Na and C_{12-15} ASO_4 Na). A significant increase in the number of aberrations was noted in female hamsters of the high-dose group after treatment with C_{12-15} ASO_4 Na. No increase was found in male animals (Unilever Research, 1977b). As all other *in vivo* studies gave no indication of a clastogenic potential, the isolated positive result in female hamsters is not considered to be of biological relevance.

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

There are no data available.

Conclusion

Alkyl sulfates of different chain lengths and with different counter ions were not mutagenic in standard bacterial and mammalian cell systems (only Na salts were tested in the latter) both in the absence and in the presence of metabolic activation. There was also no indication for a genotoxic potential of alkyl sulfates in various *in vivo* studies on mice (micronucleus assay, chromosome aberration test, and dominant lethal assay).

α-olefin sulfonates were not mutagenic in the Ames test, and did not induce chromosome aberrations *in vitro*. No genotoxicity data were available for alkane sulfonates. Based on the overall negative results in the genotoxicity assays with alkyl sulfates and α-olefin sulfonates, the absence of structural elements indicating mutagenicity, and the overall database on different types of sulfonates, which were all tested negative in mutagenicity assays, a genotoxic potential of alkane sulfonates is not expected.

Table 3-14: Genetic toxicity in vitro (bold = HPV chemical)

Test substance	Protocol Test system	Concentration Metabolic activation (MA)	Cytotoxic concentration	Result +MA / -MA	Reference
ALKYL SULFATES					
C_8 ASO_4 Na **a.i.: 40 %** **CAS 142-31-4**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	8 – 5000 µg/plate MA: + / -	5000 µg/plate	neg / neg	Henkel KGaA (1989b)
C_{8-14} ASO_4 NH_4 a.i.: 32.9 % CAS 90583-10-1	Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 2500 µg/plate MA: + / -	no data	neg / neg	Henkel KGaA (1981)
C_{8-14} ASO_4 TEA a.i.: 46 – 49 % CAS 85665-45-8	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 800 µg/plate	neg / neg	Henkel KGaA (1991j)
C_{8-16} ASO_4 Na a.i.: 29 – 31 % CAS 90583-27-0	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 1000 µg/plate	neg / neg	Henkel KGaA (1991f)
C_{10} ASO_4 Na **a.i.: 29 – 30 %** **CAS 142-87-0**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	8 - 5000 µg/plate MA: + / -	5000 µg/plate	neg / neg	Henkel KGaA (1992h)
C_{12} ASO_4 Na **a.i.: 97 %** **CAS 151-21-3**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	2.5 – 640 µg/plate MA: + / -	≥ 80 µg/plate	neg / neg	Henkel KGaA (1988d)
C_{12} ASO_4 Na **a.i.: not further specified** **CAS 151-21-3**	OECD TG 476 Mouse lymphoma cell forward mutation assay L5178Y tk^+/tk^- cells	3.125 – 100 µg/ml (4 hrs) MA: + / -	≥ 70 µg/ml	neg / neg	McGregor et al. (1988)
C_{12} ASO_4 TEA **a.i.: 40 %** **CAS 139-96-8**	Ames test S. typhimurium TA 98, TA 100	1, 10, 50, 200 or 1000 µg/plate MA: +	1000 µg/plate	neg / n.d.	Sunakawa et al. (1981)
C_{12-14} ASO_4 Na **a.i.: 63 %** **CAS 85586-07-8**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 200 µg/plate	neg / neg	Henkel KGaA (1991k)
C_{12-14} ASO_4 MEA a.i.: 30 – 31 % CAS 90583-16-7	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 800 µg/plate	neg / neg	Henkel KGaA (1991i)

Test substance	Protocol Test system	Concentration Metabolic activation (MA)	Cytotoxic concentration	Result +MA / -MA	Reference
C_{12-14} ASO_4 TEA a.i.: 40.9 – 42 % CAS 90583-18-9	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 500 µg/plate	neg / neg	Henkel KGaA (1987j)
C_{12-14} ASO_4 Mg a.i.: 30.5 % CAS 90583-23-6	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 200 µg/plate	neg / neg	Henkel KGaA (1987d)
C_{12-15} ASO_4 Na a.i.: 32 % CAS 68890-70-0	Ames test Salmonella typhimurium TA 1535, TA 1538	0 - 10000 µg/plate MA: +	10000 µg/plate	neg / n.d.	Unilever Research (1975k)
C_{12-15} ASO_4 Na a.i.: 32.5 % CAS 68890-70-0	Ames test S. typhimurium TA 1535, TA 1538	10 – 10000 µg/plate MA: +	10000 µg/plate	neg / n.d.	Unilever Research (1975k)
C_{12-16} ASO_4 Na a.i.: 89.9 % CAS 73296-89-6	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 180 µg/plate	neg / neg	Henkel KGaA (1992i)
C_{12-16} ASO_4 NH_4 a.i.: 30 % CAS 90583-12-3	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 200 µg/plate	neg / neg	Henkel KGaA (1987b)
C_{12-18} ASO_4 Na a.i.: 39.4 % CAS 68955-19-1	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 200 µg/plate	neg / neg	Henkel KGaA (1991g)
C_{12-18} ASO_4 NH_4 a.i.: 41.5 % CAS 90583-13-4	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 1000 µg/plate	neg / neg	Henkel KGaA (1991d)
C_{14} ASO_4 Na a.i.: not further specified CAS 1191-50-0	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0.25 – 8 µl/ml MA: + / -	≥ 4 µl/ml	neg / neg	Procter & Gamble Co. (1979)
C_{14} ASO_4 Na a.i.: not further specified CAS 1191-50-0	OECD TG 476 Mouse lymphoma cell forward mutation assay L5178Y tk^+/tk^- cells	0.06 – 1 µl/ml MA: + / -	≥ 0.13 µl/ml	neg / neg	Procter & Gamble Co. (1981)
C_{16} ASO_4 Na a.i.: not further specified CAS 1120-01-0	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0.25 – 8 µl/ml MA: + / -	≥ 2 µl/ml	neg / neg	Procter & Gamble Co. (1979)
C_{16} ASO_4 Na a.i.: not further specified CAS 1120-01-0	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	15.6 – 2000 µg/plate MA: + / -	no data	neg / neg	Procter & Gamble Co. (1976c)
C_{16} ASO_4 Na a.i.: not further	OECD TG 476 Mouse lymphoma cell forward mutation assay	0.01 – 1 µl/ml MA: + / -	≥ 0.09 µl/ml	neg / neg	Procter & Gamble Co. (1981)

Test substance	Protocol Test system	Concentration Metabolic activation (MA)	Cytotoxic concentration	Result +MA / -MA	Reference
specified CAS 1120-01-0	L5178Y tk^+/tk^- cells				
C_{16-18} ASO_4 Na **a.i.: 94.3 %** **CAS 68955-20-4**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	≥ 200 µg/plate	neg / neg	Henkel KGaA (1992d, 1995)
C_{14-18} and C_{18}= ASO_4 Na a.i.: 57 – 60 % CAS 90583-31-6	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA: + / -	5000 µg/plate	neg / neg	Henkel KGaA (1991c)
ALKANE SULFONATES					
no data available					
α -OLEFIN SULFONATES					
C_{14-16} =/$OHASO_3$ Na **a.i.: not further specified** **CAS 68439-57-6**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 5000 µg/plate MA : + / -	≥ 500 µg/plate	neg / neg	Kao Co. (1996)
C_{14-16} =/$OHASO_3$ Na **a.i.: ca. 40 %** **CAS 68439-57-6**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537, TA 1538	0 – 10000 µg/plate MA: + / -	≥ 500 µg/plate	neg / neg	Hoechst AG (1988a)
C_{14-16} =/$OHASO_3$ Na **a.i.: ca. 40 %** **CAS 68439-57-6**	OECD TG 471 Bacterial reverse mutation assay E. coli WP2uvrA	0 – 10000 µg/plate MA: + / -	> 10000 µg/plate	neg / neg	Hoechst AG (1988a)
C_{14-16} =/$OHASO_3$ Na **a.i.: ca. 40 %** **CAS 68439-57-6**	OECD TG 473 Chromosomal aberration test Chinese hamster V79 cells	0 – 200 µg/ml MA: + / -	≥ 250 µg/ml	neg / neg	Hoechst AG (1989)
C_{14} =/$OHASO_3$ Na **a.i.: 90.6 %** **CAS 93686-14-7**	OECD TG 471 Ames test S. typhimurium TA 98, TA 100, TA 1535, TA 1537	0 – 1250 µg/plate MA : + / -	≥ 39.1 µg/plate	neg / neg	Lion Co. (2004a)
C_{14} =/$OHASO_3$ Na **a.i.: 90.6 %** **CAS 93686-14-7**	OECD TG 471 Bacterial reverse mutation assay E. coli WP2uvrA	0 – 1250 µg/plate MA : + / -	≥ 156 µg/plate	neg / neg	Lion Co. (2004a)
C_{14} =/$OHASO_3$ Na **a.i.: 90.6 %** **CAS 93686-14-7**	OECD TG 473 Chromosomal aberration test Chinese hamster CHL cells	0 – 250 µg/plate MA : + / -	≥ 187.5 µg/ml	neg / neg	Lion Co. (2004c)

Table 3-15: Genetic toxicity *in vivo (bold = HPV chemical)*

Test substance	Protocol Test system	Species Number of animals	Application Dosage (for a.i.) Exposure period	Result	Comment	Reference
ALKYLSULFATES						
C_{12} ASO_4 Na a.i.: 0, 0.56 or 1.13 % CAS 151-21-3	Chromosome aberration assay	6 Colworth-Wistar rats/sex/dose	oral feed via diet ca. 0, 500 or 1000 mg/kg bw/day 90 days	negative	no increase in rearrangements, chromatid gaps and breaks, isochromatide gaps and breaks	Unilever Research (1976a); Hope (1977)
C_{12} ASO_4 Na a.i.: no further data CAS 151-21-3	OECD TG 478 Dominant lethal assay	15 male CD-1 mice/group (dosed and positive controls; 30 as negative controls)	gavage single dosing with 0, 120, 380 or 1200 mg/kg bw	negative	no adverse effects on pregnancy frequency, number of implantations or frequency of early deaths	Unilever Research (1976h, 1976m)
C_{12-14} ASO_4 TEA a.i.: 40.9 – 42 % CAS 90583-18-9	OECD TG 474 Micronucleus assay	7 CFW 1 mice/sex	gavage single dosing with 1636 mg/kg bw (4000 mg/kg bw) 24, 48 or 72 hrs two additional groups were dosed with 400 or 2000 mg/kg bw; sampling time: 24 hrs	negative	4000 mg/kg: group mean micronucleated cell count was comparable with controls. Therefore, the two additional dose levels were not evaluated	Henkel KGaA (1987k)
C_{12-15} ASO_4 Na a.i.: 10 % CAS 68890-70-0	Chromosome aberration assay	8 hamsters/sex/dose	gavage single dosing with 0, 1250 or 2500 mg/kg bw 24 hrs	positive	2500 mg/kg: statistically significantly increased (level of significance not stated) number of divisions with aberrations in females when compared with negative controls	Unilever Research (1977b)
C_{12-15} ASO_4 Na a.i.: 0 or 1.13 % CAS 68890-70-0	Chromosome aberration assay	6 Colworth-Wistar rats / sex	oral feed via diet ca. 0 or 1000 mg/kg bw/day 90 days	negative	no increase in rearrangements, chromatid gaps and breaks, isochromatide gaps and breaks	Unilever Research (1976a, 1976h); Hope (1977)
C_{12-15} ASO_4 Na a.i.: 0 or 1.13 % CAS 68890-70-0	Chromosome aberration assay	6 Colworth-Wistar rats / sex	oral feed via diet ca. 0 or 1000 mg/kg bw/day 90 days	negative	no increase in rearrangements, chromatid gaps and breaks, isochromatide gaps and breaks	Unilever Research (1976a, 1976h); Hope (1977)
C_{12-15} ASO_4 Na a.i.: no further data CAS 68890-70-0	OECD TG 478 Dominant lethal assay	15 male CD-1 mice/group (dosed and positive controls; 30 as negative controls)	gavage single dosing with 0, 300, 960 or 3010 mg/kg bw	negative	Dosing caused an increase in early deaths in embryos of females mated on week 4 (evident using 3 methods of analysis of the data but a dose-related effect was only established by one method of analysis)	Unilever Research (1976h; 1976m)
C_{12-15} ASO_4 Na a.i.: no further data CAS 68890-70-0	OECD TG 478 Dominant lethal assay	15 male CD-1 mice/group (dosed and positive controls; 30 as negative controls)	gavage single dosing with 0, 310, 980 or 3050 mg/kg	negative	Dosing gave no indication of any dominant lethal mutation (assessed from early / late deaths and live implants in females mated over 8 weeks with treated males)	Unilever Research (1976h. 1976m)

Test substance	Protocol Test system	Species Number of animals	Application Dosage (for a.i.) Exposure period	Result	Comment	Reference
C_{16-18} ASO_4 Na **a.i.: 55 %** **CAS 68955-20-4**	OECD TG 474 Micronucleus assay	7 CFW 1 mice/sex	gavage single dosing with 2200 mg/kg bw (4000 mg TS/kg bw) 24, 48 or 72 hrs two additional groups were dosed with 400 or 2000 mg TS/kg bw; sampling time: 24 hrs	negative	4000 mg/kg: group mean micro-nucleated cell count was comparable with controls. Therefore, the two additional dose levels were not evaluated	Henkel KGaA (1986b)
ALKANE SULFONATES						
no data available						
α-OLEFIN SULFONATES						
no data available						

3.1.7 Carcinogenicity

Studies in Animals

Dermal

The individual results of these studies are summarized in Table 3-16.

Alkyl sulfates

There are no data are available.

Alkane sulfonates

There are no data are available.

α-Olefin sulfonates

In a study, of which only a short summary is available, groups of mice were treated 3 times weekly with 0.02 ml of C_{14-16}- or C_{14-18}- α-olefin sulfonate at concentrations of 0, 20 or 25 % for 92 weeks. The test material was applied to approximately 1 cm^2 of exposed skin. Final necropsies were conducted at a mean survival of 30% per group (at ca. 19 months). Histopathology failed to demonstrate carcinogenicity for either sample (International Alpha Olefin Sulfonate Group, 1980).

In a 2-year study, Long-Evans rats (50 animals/sex/group) were treated twice weekly with 1 ml C_{14-16} =/$OHASO_3$ Na/kg bw at a concentration of 10 % in de-ionized water (ca. 100 mg/kg bw). The application caused no carcinogenic effects and apart from decreased relative kidney weighs in dosed males no adverse effects concerning mortality, mean body weights, food consumption, hematology, urinalysis, and post-mortem observations were found (SDA, 1979).

Oral

The individual results of these studies are summarized in Table 3-17.

Alkyl sulfates

For the alkyl sulfates two reliable studies are available.

With C_{12-15} ASO_4 Na two 2 year oral feeding studies with test materials of a slightly differing chain length distribution were performed, where 45 Wistar rats/sex/group were dosed with 0, 0.015, 0.15 or 1.5 % in the diet (ca. 0, 11, 113 or 1125 mg/kg bw). In both studies the survival rate was about 70 % and there was no indication that the substance caused an increase in tumor incidence or a change in the spectrum of the spontaneous tumour types. Animals dosed with 1.5 % showed a decrease in food and water intake as well as decreased growth rates. In these groups the total number of tumours and total number of rats with tumours was decreased, which is probably due to a decreased caloric intake. Other reported effects were increased absolute and relative liver weights, hypertrophy of the hepatic parenchyma, and a decrease in the incidence and severity of chronic nephropathy and nephrocalcinosis (Unilever Research, 1995a, 1995b).

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

C_{14-16} =/$OHASO_3$ Na was tested in a 2 year study with Sprague-Dawley derived CFY rats (50 animals/sex/group), where the animals were dosed with 0, 1000, 2500 or 5000 ppm (corresponding to up to 259 mg/kg bw/day). The survival rate was in the range of 38 – 54 %. Although there was an increase of pancreatic islet cell tumours (m), adrenal tumours (m) and thyroid tumours (f), these increases were not attributed to the substance application, as there was no dose response (increases were noted in low- and mid-dosed animals, while the incidences in high-dosed rats were comparable with controls). Furthermore, incidences of islet cell tumours as high as those seen in this study have been recorded among male control CFY rats used in other studies carried out in the same laboratory (Lion Co., 1975; Hunter & Benson, 1976).

Conclusion

Alkyl sulfates were not carcinogenic in good quality feeding studies with male and female Wistar rats were fed diets with C_{12-15} ASO_4 Na for two years (corresponding to doses of up to 1125 mg /kg bw/day). No carcinogenicity studies were available for the alkane sulfonates.

α-olefin sulfonates were not carcinogenic in mice and rats after dermal application, and in rats after oral exposure. Dermal applications in mice were carried out 3 times weekly for 92 weeks with a volume of 0.02 ml of either C_{14-16} – or C_{14-18} α-olefin sulfonates at concentrations of 20 or 25%. Rats were treated twice weekly for 104 weeks with a 10% solution of C_{14-16} =/$OHASO_3$ Na. In the oral study, Sprague-Dawley rats were dosed with up to 259 mg C_{14-16} =/$OHASO_3$ Na/kg bw/day.

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Table 3-16: Carcinogenicity - dermal studies in experimental animals (bold = HPV chemical)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	Results	Reference
ALKYLSULFATES					
no data available					
ALKANE SULFONATES					
no data available					
α-OLEFIN SULFONATES					
C_{14-16} =/$OHASO_3$ Na and C_{14-18} =/$OHASO_3$ Na a.i.: 0, 20 or 25 % CAS 68439-57-6 CAS 863609-89-6	mouse	92 weeks	0.02 ml, 3 times per week to approximately 1 cm^2 of skin; final necropsies at a mean survival of 30% per group (ca. 19 months)	No indication of a carcinogenic activity in histopathology.	International Alpha Olefin Sulfonate Group (1980) As quoted in Ter Haar (1983)
C_{14-16} =/$OHASO_3$ Na a.i.: 0 or 10 % CAS 68439-57-6	rat Long-Evans 50 animals / sex / group	104 weeks	1 ml/kg bw with 0 or 10 % twice weekly	The application to the clipped dorsal surface caused no carcinogenic effects. Mortality, mean body weights, food consumption, hematology, urinalysis, and post-mortem observations were comparable in all groups. In dosed males relative kidney weights were significantly decreased when compared with controls.	SDA (1979)

Table 3-17: Carcinogenicity – oral studies in experimental animals (bold = HPV chemical)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	Results	Reference
ALKYLSULFATES					
C_{12-15} ASO_4 Na a.i.: 0, 0.015, 0.15 or 1.5 % CAS 68890-70-0	Rat Wistar 45 rats/sex/dose	104 weeks	oral feed ca. 0, 11, 113 or 1125 mg/kg bw/day	neoplasia was most common cause of deaths in animals which died during the study, but this was not enhanced by treatment (e.g. pituitary 25, mammary gland 13, brain 9, subcutis 6, lymphoreticular tissue 6; total neoplasms: 114, 107, 107, 92); survival was highest at 1.5 % (73.3 %) and lowest at 0.15 % (64.4 %) 1125 mg/kg bw: food/water intake and growth rate (m/f) ↓; total number of tumours and total number of rats with tumours (m/f) ↓; SGOT, ALT, LDH and ALP values (m) ↑; liver: absolute/relative weights ↑; zonal/diffuse parenchymal hypertrophy (m/f) ↑; pigmented lipid granulomata (f) ↑; focal coagulative/hemorrhage necrosis (m) ↑; extramedullary erythopoiesis (m/f) ↓; kidneys: severity and/or incidence of chronic nephropathy, pelvic nephrocalcinosis and pelvic epithelial hyperplasia (m/f) ↓; heart: severity and/or incidence of arterial medial hypertrophy and patchy myocardial fibrosis (m/f) ↓; spleen: hemosiderin deposition (m) ↑; myelopoiesis (m/f) ↓; stem cell hyperplasia (m) ↓; brain: relative weights ↑; testes: relative weights ↑; severity and/or incidence of focal/multifocal arteritis ↓	Unilever Research (1995a)
C_{12-15} ASO_4 Na a.i.: 0, 0.015, 0.15 or 1.5 % CAS 68890-70-0	rat Wistar 45 rats/sex/dose	104 weeks	oral feed ca. 0, 11, 113 or 1125 mg/kg bw	survival was highest at 1.5 % (78.9 %) and lowest at 0.15 % (60 %) 1125 mg/kg bw: food/water intake and growth rate (m/f) ↓; total number of tumours and total number of rats with tumours in f ↓ due to reduction in liver and lymphoreticular tumours; total number of pancreatic (exocrine and islet cell) tumours in m ↑ (not significant when each type was considered separately); total white cell count (f) ↓; ALT and ALP values (m) ↑; LDH and HDB values (f) ↓; liver: absolute/relative weights (m/f) ↑; zonal/diffuse parenchymal hypertrophy (m/f) ↑; pigmented lipid granulomata (f) ↑; focal coagulative/ hemorrhage necrosis (m) ↑; spleen: relative weights (m) ↓; erythropoiesis, hemosiderin deposition, myelopoiesis and stem cell hyperplasia (f) ↓; red pulp hemosiderin (f) ↑; heart: relative weights (m) ↓; severity and/or incidence of arterial medial hypertrophy ↓; kidneys: relative weights (m) ↓; severity and/or incidence of chronic nephropathy and pelvic nephrocalcinosis ↓; adrenals: relative weights (m) ↓; testes: relative weights ↑	Unilever Research (1995b)
ALKANE SULFONATES					
no data available					
α-OLEFIN SULFONATES					

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	Results	Reference
C_{14-16} =/OHASO$_3$ Na mixture of alkenyl sulfonate and hydroxyalkane sulfonate (60.4:39.6 % w/w) a.i.: 97.93 % CAS 68439-57-6	rat Sprague-Dawley CFY 50 males and females per dose group	104 weeks	in diet 0, 1000, 2500, or 5000 ppm (m: 0, 39, 96, or 195 mg/kg bw/day; f: 0, 57, 132, or 259 mg/kg bw/day)	Mortality after 104 weeks (m/f): 0 ppm: 22 / 25 1000 ppm: 23 / 19 2500 ppm: 27 / 27 5000 ppm: 20 / 20 Not dose-related increases of pancreatic islet cell tumours (m), adrenal tumours (m) and thyroid tumours (f). These increases were noted in low- and mid-dosed animals, while the incidences in high-dosed rats were comparable with controls. ≤ 5000 ppm: no adverse clinical, hematological or clinical chemistry effects; no adverse histopathological findings (complete necropsy on all surviving rats) 5000 ppm: food intake during the first year of treatment (f) ↓; body weight gain in weeks 14 – 26 (m/f) ↓	Lion Co. (1975); Hunter & Benson (1976)

3.1.8 Toxicity for Reproduction

Studies in Animals

Effects on Fertility

Alkyl sulfates

Hemsworth et al. (1981) fed groups of 10 male Swiss albino mice/dose with either 1 % of C_{12} ASO_4 Na for 2 weeks or with 0.1 % of C_{12} ASO_4 Na for 6 weeks to ensure that germ cells were exposed at any stage of development. 1, 2 or 3 weeks after dosing the animals of each group were mated with a females (replaced weekly for three weeks). At the highest dose level body weights were significantly decreased, while the treatment caused no adverse effects on fertility (i.e. impairment of epididymal spermatozoa). A NOAEL of 1000 mg/kg bw/day can be derived for this endpoint.

Repeated oral dose 13 week-studies with C_{12-15} ASO_4 Na (CAS 68890-70-0), C_{16-18} ASO_4 Na (CAS 68955-20-4) and C_{13-15} ASO_4 Na (CAS 86014-79-1) gave no indication of adverse effects on reproductive organs (Unilever Research, 1976d, 1977d, 1977e). At very high doses (around or above 1000 mg/kg bw/day) increases in relative (but not absolute) testes weights were noted; this effect was not considered as adverse but was attributed to a decreased body fat / body weight; there were also no adverse histopathological findings at necropsy (cf. chapter on repeated dose toxicity for details on study conduct and results).

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

In male and female CD rats a 2-generation reproductive toxicity study was performed with a mixture of C_{14}:C_{16}:C_{18} blend (1:1:1 ratio) of α-olefin sulfonate, Mg salt (Lion Co., 1980). The animals were continuously dosed with 0, 1250, 2500 or 5000 ppm in the diet with a protocol comparable to OECD TG 416. Two batches of the α-olefin sulfonate, Mg salt with an active ingredient content of 94.88 – 95.54 % were used and the calculated intakes were given as follows:

		Test material consumption (mg/kg bw/day)	
Generation	**Sex**	**Week 1**	**Week 13**
F_0	Males	0, 189, 357 or 727	0, 63, 127 or 250
	Females	0, 186, 350 or 679	0, 79, 160 or 320
F_1	Males	0, 232, 458 or 891	0, 68, 131 or 261
	Females	0, 232, 462 or 871	0, 85, 165 or 338
F_2	Males	0, 248, 474 or 1040	0, 66, 131 or 266
	Females	0, 242, 492 or 961	0, 82, 165 or 370

Males and females of the F_0 parental generation were treated for 13 weeks prior to mating, then through gestation and lactation of two successive litters (F_{1A} and F_{1B}). Two further litters (F_{2A} and F_{2B}) were produced with selected animals of the second litter as parents. Then rats from the latter were selected to form an F_2 generation, which was treated for 13 weeks and subjected to a histopathological examination. For the F_0 and F_1 generations, 12 males per dose group were each paired with 2 females for mating (24 females per group), yielding about 20 pregnant females per dose group.

Even at the highest dose tested (5000 ppm) no adverse effects concerning general health, food and water intake, food utilization, weight gain, reproductive performance and fertility were observed. Terminal necropsy of adults and offspring revealed no treatment-related abnormalities and also the

histopathological examination of tissues from the F_2 generation gave no adverse treatment-related effects.

Developmental Toxicity

The individual results concerning developmental toxicity are summarized in Table 3-18.

Alkyl sulfates

For the alkyl sulfates several reliable studies with oral dosing by gavage in rats, mice and rabbits are available for C_{12} ASO_4 Na (Palmer et al., 1975a; Unilever Research, 1976i), C_{12-14} ASO_4 Na (Unilever Research, 1987), C_{12-15} ASO_4 Na (Unilever Research, 1976j; 1977g), C_{13-15} ASO_4 Na (Unilever Research, 1979), C_{15-16} AS Na (Unilever Research, 1986) and C_{16-18} ASO_4 Na (Unilever Research, 1978). Effects on litter parameters were restricted to doses that caused significant maternal toxicity (anorexia, weight loss, and death at doses between 300 and 500 mg/kg bw for rats and at 300 mg/kg bw/day for mice and rabbits), the principal effects being higher foetal loss and increased incidences of total litter losses. The incidences of malformations and visceral and skeletal anomalies were unaffected apart for a higher incidence of skeletal variation in mice at 600 mg/kg bw/day indicative of a delayed development. The NOAELs for developmental toxicity were at 250 mg/kg bw/day for rats, and at 300 mg/kg bw/day for mice and rabbits.

Alkane sulfonates

There are no data available.

α-Olefin sulfonates

The developmental toxicity of C_{14-16} =/$OHASO_3$ Na (mixture of alkenyl sulfonate and hydroxy-alkane sulfonate [60.4:39.6 % w/w]) was studied in rats, mice and rabbits (Palmer et al., 1975b). The substance was administered by gavage during days 6-15 of pregnancy in rats and mice, and days 6-18 of pregnancy in rabbits. The doses were 0.2, 2, 300 and 600 mg/kg bw/day. In rats, no effects on dams or offspring were seen up to and including the highest tested dose of 600 mg/kg bw/day. In mice and rabbits, maternal toxicity in the form of retarded weight gain or weight loss, death and/or total litter loss was apparent at 600 mg/kg bw/day and to a lesser extent at 300 mg/kg bw/day. Litter parameters were unaffected at doses that were either non-toxic or only slightly toxic to the dam, i.e. 0.2 and 2 mg/kg bw/day in rabbits and mice. Higher foetal loss occurred in mice at 300 and 600 mg/kg bw/day. Lower mean pup weight was observed in rabbits at 300 mg/kg bw/day and in mice at 600 mg/kg bw/day. The incidences of major malformations and of minor visceral and skeletal anomalies and skeletal variants (extra ribbed pups) was unaffected apart from higher incidences of minor skeletal anomalies and variants in rabbits at 300 mg/(kg bw/day and of cleft palates in mice at 600 mg/kg bw/day. The NOAELs for maternal toxicity were 600 mg/kg bw/day in rats, and 2 mg/kg bw/day in rabbits and mice. The NOAELs for developmental toxicity were 600 mg/kg bw/day in rats, and 2 mg/kg bw/day in rabbits and mice.

Conclusion

No fertility studies were performed with alkyl sulfates and alkane sulfonates. Oral dosing of male mice with C_{12} ASO_4 Na (1 % over 2 or 0.1 % over 6 weeks) caused no adverse effects on epididymal spermatozoa, and a NOAEL for male fertility was derived at 1000 mg a.i./kg bw/day in an earlier SIDS document for sodium dodecyl sulfate. No indication for adverse effects on reproductive organs was found in various oral studies with different alkyl sulfates. For the α-olefin sulfonates a modern two generation reproductive toxicity study in male and female CD rats was performed with a mixture of C_{14}:C_{16}:C_{18} blend (1:1:1 ratio) of α-olefin sulfonate, Mg salt. Two batches with an active ingredient content of ca. 95 % were used and the animals were continuously dosed with 0, 1250, 2500 or 5000 ppm (corresponding to about 1040 mg a.i./kg bw/day) in the diet

with a protocol comparable to OECD TG 416. The animals showed no adverse effects up to and including the highest test concentration of 5000 ppm.

The developmental toxicity of various alkyl sulfates (C_{12} ASO_4 Na, C_{12-14} ASO_4 Na, C_{12-15} ASO_4, C_{13-15} ASO_4 Na, C_{15-16} AS Na, C_{16-18} ASO_4 Na) was tested on rats, rabbits and mice. Effects on litter parameters were restricted to doses that caused significant maternal toxicity (anorexia, weight loss, and death at doses between 300 and 500 mg a.i./kg bw for rats and at 300 mg a.i./kg bw/day for mice and rabbits), the principal effects being higher fetal loss and increased incidences of total litter losses. The incidences of malformations and visceral and skeletal anomalies were unaffected apart from a higher incidence of delayed ossification or skeletal variation in mice at $\geq$ 500 mg a.i./kg bw/day indicative of a delayed development. The lowest reliable NOAEL for maternal toxicity was about 200 mg a.i./kg bw/day in rats, while the lowest NOAELs in offspring were 250 mg a.i./kg bw/day in rats and 300 mg a.i./kg bw/day for mice and rabbits.

For the α-olefin sulfonates no adverse effects were reported in rats (dams and offspring) dosed with up to 600 mg a.i./kg bw/day of C_{14-16} =/$OHASO_3$ Na during days 6-15 of pregnancy, i.e. the NOAEL was 600 mg a.i./kg bw/day both for maternal and developmental toxicity. From a parallel study with mice and rabbits no clear NOAEL can be derived due to an unusual spreading of the applied doses (0, 0.2, 2, 300 and 600 mg a.i./kg bw/day). At 2 mg a.i./kg bw/day no adverse effects were found, while at 300 mg a.i./kg bw/day adverse effects both in dams and offspring were observed.

No data were available for the reproductive and developmental toxicity of alkane sulfonates. Based on the available data, the similar toxicokinetic properties and a comparable metabolism of the alkyl sulfates and alkane sulfonates, alkane sulfonates are not considered to be developmental toxicants.

Although the database for category members with $C < 12$ is limited, the available data are indicating no risk as the substances have comparable toxicokinetic properties and metabolic pathways. In addition, longer-term studies gave no indication for adverse effects on reproductive organs with different alkyl sulphates.

Table 3-18: Developmental Toxicity – Teratogenicity in experimental animals (substances sorted by chain length; bold = HPV chemical)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
ALKYL SULFATES							
C_{12} ASO_4 Na **CAS 151-21-3**	rat CD 20 animals/group	day 6 – 15 of gestation termination on gd 20	gavage 0, 0.2, 2, 300 or 600 mg/kg bw/day	Maternal: 2 Offspring: 600	Maternal: 300 Offspring: > 600	Maternal data: ≥ 300 mg/kg: slight to moderate toxicity 600 mg/kg mortality 3/20 Offspring: 600 mg/kg: no adverse effects	Palmer et al. (1975a, 1975b)
C_{12} ASO_4 Na **CAS 151-21-3**	mouse CD-1 20 animals/group	day 6 – 15 of gestation termination on gd 17	gavage 0, 0.2, 2, 300 or 600 mg/kg bw/day	Maternal: 2 Offspring: 300	Maternal: 300 Offspring: 600	Maternal data: 300 mg/kg: mortality 1/20 600 mg/kg: mortality 4/20 Offspring: ≤ 300 mg/kg: no adverse effects on foetal morphogenesis 600 mg/kg: total resorption and/or increased incidence of litter loss	Palmer et al. (1975a, 1975b)
C_{12} ASO_4 Na **CAS 151-21-3**	rabbit NZW 13 animals/group	day 6 – 18 of gestation termination on gd 29	gavage 0, 0.2, 2, 300 or 600 mg/kg bw/day	Maternal: 2 Offspring: 300	Maternal: 300 Offspring: 600	Maternal data: 300 mg/kg: mortality 1/13 ≥ 300 mg/kg: diarrhea, anorexia, weight loss, cachexia, foetal loss 600 mg/kg: mortality 11/13 Offspring: ≤ 300 mg/kg: no adverse effects on foetal morphogenesis 600 mg/kg: abortion, total resorption and/or increased incidence of litter loss	Palmer et al. (1975a, 1975b)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
C_{12} ASO_4 Na **CAS 151-21-3**	rat Wistar 15 animals/group (10 dissection, 5 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 63, 125, 250 or 500 mg/kg bw/day	Maternal: 250 Offspring: 500	Maternal: 500 Offspring: 500	Maternal data: 500 mg/kg: diarrhea; feed intake ↓; mean body weight gain ↓; mortality ↑ (5/15 due to gastrointestinal irritation / diffuse hemorrhages of the stomach / congestion of the lungs) Offspring: ≤ 500 mg/kg: no increased incidence of soft tissue or skeletal defects when compared with untreated controls 500 mg/kg: mean placental weights ↓	Unilever Research (1976i)
C_{12-14} ASO_4 Na **CAS 85586-07-8**	rat Wistar 20 animals/group (15 dissection, 5 natural parturition) 40 animals as controls (30 dissection, 10 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 63, 125, 250 or 500 mg/kg bw	Maternal: 250 Offspring: 250	Maternal: 500 Offspring: 500	Maternal data: 500 mg/kg: diarrhea; feed intake ↓; mean body weight gain ↓; mortality ↑ (one death and two animals were killed prior to full term) Offspring: 500 mg/kg: intrauterine deaths ↑; live foetal body weights ↓; toxic retardation with delayed ossification and increased incidence of supernumerary cervical ribs and shortened thoracic ribs	Unilever Research (1987)
C_{12-15} ASO_4 Na **CAS 68890-70-0**	rat Wistar 15 animals/group (10 dissection, 5 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 47, 94, 375 or 563 mg/kg bw/day	Maternal: 375 Offspring: 375	Maternal: 563 Offspring: 563	Maternal data: ≥ 375 mg/kg: salivation and lacrimation 563 mg/kg: diarrhea; feed intake ↓; body weight gain ↓ Offspring: 563 mg/kg: mean foetal body weights ↓	Unilever Research (1977g)
C_{12-15} ASO_4 Na **CAS 68890-70-0**	rat Wistar 15 animals/group (10 dissection, 5 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 63, 125, 250 or 500 mg/kg bw	Maternal: 250 Offspring: 500	Maternal: 500 Offspring: > 500	Maternal data: 500 mg/kg: diarrhea; feed intake ↓; body weight gain ↓ Offspring: ≤ 500 mg/kg: no increased incidence of soft tissue or skeletal defects when compared with untreated controls	Unilever Research (1976j)
C_{13-15} ASO_4 Na CAS 86014-79-1	rat Wistar 15 animals/group (10 dissection, 5 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 49, 98, 195 or 390 mg/kg bw/day	Maternal: 195 Offspring: 390	Maternal: 390 Offspring: > 390	Maternal data: 390 mg/kg: diarrhea; salivation; feed intake ↓ Offspring: ≤ 390 mg/kg: no increased incidence of soft tissue or skeletal defects when compared with untreated controls	Unilever Research (1979)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
$C_{15\text{-}16}$ ASO_4 a.i.: 31.6 % CAS 99999-99-9	rat Wistar 15 animals/group (10 dissection, 5 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 125, 250, 500, 750 or 1000 mg/kg bw/day	Maternal: 250 Offspring: 750	Maternal: 500 Offspring: 1000	Maternal data: 250 mg/kg: number of corpora lutea ↑ ≥ 500 mg/kg: diarrhea, wheeziness 750 mg/kg: mean body weight ↓; feed intake ↓ ≥ 750 mg/kg: mean body weight gain ↓ 1000 mg/kg: mortality ↑ (5/15) Offspring: 1000 mg/kg: post-implantation loss per pregnancy and intrauterine deaths ↑; total number of foetuses with skeletal defects/anomalies/variants (mainly variant sternebrae) ↑; number of ossified cervical centra ↓; number of ossified phalanges of the fore-paws ↓	Unilever Research (1986)
$C_{16\text{-}18}$ ASO_4 Na **CAS 68955-20-4**	rat Wistar 15 animals/group (10 dissection, 5 natural parturition)	day 6 – 15 of gestation termination on gd 21 or up to weaning day 21	gavage 0, 112, 225, 450 or 675 mg/kg bw	Maternal: 225 Offspring: 675	Maternal: 450 Offspring: > 675	Maternal data: ≥ 450 mg/kg: mean body weight gain ↓ 675 mg/kg: diarrhea Offspring: 450 mg/kg: mean placental weights ↓ (m) ≤ 675 mg/kg: no increased incidence of soft tissue or skeletal defects when compared with untreated controls	Unilever Research (1978)
ALKANE SULFONATES							
no data available							
α-OLEFIN SULFONATES							
$C_{14\text{-}16}$ =/OHASO_3 Na **mixture of alkenyl sulfonate and hydroxy-alkane sulfonate (60.4:39.6 % w/w)** **CAS 68439-57-6**	rat CD 20 animals/group	day 6 – 15 of gestation termination on gd 20	gavage 0, 0.2, 2, 300 or 600 mg/kg bw/day	Maternal: 600 Offspring: 600	Maternal: > 600 Offspring: > 600	Maternal data: ≤ 600 mg/kg: no adverse effects on mortality and bodyweight gain; no adverse effects at necropsy Offspring: ≤ 600 mg/kg: no adverse effects on litter size, embryonic deaths, litter and mean pup weights; no malformations, anomalies and skeletal variants	Palmer et al. (1975a, 1975b)

Test substance	Species / Strain / Number of animals in study / Sex	Duration	Dosage	NOAEL (mg/kg bw/day for a.i.)	LOAEL (mg/kg bw/day for a.i.)	Results	Reference
C_{14-16} =/OHASO$_3$ Na mixture of alkenyl sulfonate and hydroxy-alkane sulfonate (60.4:39.6 % w/w) CAS 68439-57-6	mouse CD-1 20 animals/group	day 6 – 15 of gestation termination on gd 17	gavage 0, 0.2, 2, 300 or 600 mg/kg bw/day	Maternal: 2 Offspring: 2	Maternal: 300 Offspring: 300	Maternal data: ≥ 300 mg/kg: piloerection; activity ↓ 600 mg/kg: mortality ↑ (0/0/0/0/6) Offspring: ≤ 2 mg/kg: no effects on litter parameters such as litter size, embryonic deaths, litter weight, mean pup weight ≥ 300 mg/kg: total litter loss ↑ (2/1/1/6/5); cleft palate in 2 pups (one litter) at 300 mg/kg and in 4 pups (three litters) at 600 mg/kg 600 mg/kg: significantly increased incidence of skeletal anomalies (mainly generally reduced ossification; a higher incidence of skeletal anomalies [retarded ossification of occipitals] also was recorded with other dosages)	Palmer et al. (1975a, 1975b)
C_{14-16} =/OHASO$_3$ Na mixture of alkenyl sulfonate and hydroxy-alkane sulfonate (60.4:39.6 % w/w) CAS 68439-57-6	rabbit NZW 13 animals/group	day 6 – 18 of gestation termination on gd 29	gavage 0, 0.2, 2, 300 or 600 mg/kg bw/day	Maternal: 2 Offspring: 2	Maternal: 300 Offspring: 300	Maternal data: ≥ 300 mg/kg: mortality ↑ (0/0/0/1/13); anorexia; diarrhea 600 mg/kg: death of all dams Offspring: ≤ 2 mg/kg: no effects on litter parameters such as litter size, embryonic deaths, litter weight, mean pup weight ≥ 300 mg/kg: mean body weights ↓; minor skeletal anomalies (not further specified) ↑ (7, 10, 5 or 23 %); proportion of pups with extra lumbar rib ↑ (59, 63, 53 or 87 %) 600 mg/kg no foetuses due to death of dams	Palmer et al. (1975a, 1975b)

3.2 Initial Assessment for Human Health

Alkyl Sulfates, alkane sulfonates and α-olefin sulfonates are well absorbed after ingestion; penetration through the skin is however poor. After absorption, these chemicals are distributed mainly to the liver. Alkyl sulfates, alkane sulfonates and most probably also α-olefin sulfonates are metabolized by cytochrome P450-dependent ω-oxidation and subsequent ß-oxidation of the aliphatic fatty acids. End products of the oxidation are a C_4 sulfate or sulfonate (even numbered chain lengths) and a C_3 or C_5 sulfate or sulfonate (odd numbered chain lengths). For the alkyl sulfates in addition sulfate is formed as a metabolite. The metabolites are rapidly excreted in the urine.

Acute dermal LD_{50} values in rabbits were 200 mg a.i. (active ingredients)/kg bw for the C_{12}- and greater than 500 mg a.i./kg bw for the C_{12-13}- and C_{10-16}-alkyl sulfates, respectively; apart from moderate to severe skin irritation, clinical signs included tremor, tonic-clonic convulsions, respiratory failure, and body weight loss in the study with the C_{12}-alkyl sulfate and decreased body weights after administration of the C_{10-16}-alkyl sulfates. No data are available for alkane sulfonates but due to a comparable metabolism and effect concentrations in long-term studies effect concentrations are expected to be in the same range as found for alkyl sulfates. No specific systemic toxicity occurred in acute dermal toxicity studies with the α-olefin sulfonate C_{14-16}=/$OHASO_3$ Na on rats or rabbits at the highest tested dose level (740 mg a.i./kg bw in rats, 2325 mg a.i./kg bw in rabbits).

Acute oral LD_{50} values in rats and/or mice of alkyl sulfates were between 290 and 580 mg a.i./kg bw for C_{10}, between 1000 and 2000 mg a.i./kg bw for C_{10-16}, and C_{12}, greater than 2000 mg a.i./kg bw for C_{12-14}, C_{12-15}, C_{12-16}, C_{12-18} and C_{16-18}, and greater than 5000 mg a.i./kg bw for C_{14-18} and $_{16-18}$=alkyl sulfates. The counter ion does not appear to influence the toxicity in a substantial way. The clinical signs observed were non-specific (piloerection, lethargy, decreased motor activity and respiratory rate, diarrhea). At necropsy the major findings were irritation of the gastrointestinal tract and anemia of inner organs. The LD_{50} in rats of the C_8 alkane sulfonate (sodium salt) was > 5000 mg a.i./kg bw with no clinical signs of intoxication and no adverse findings at necropsy reported. LD_{50} values in rats for the C_{14-16}-α-olefin sulfonates (sodium salts) were between 578 and 2200 mg a.i./kg bw. Based on limited data, the acute oral LD_{50} values of alkane sulfonates and α-olefin sulfonates of comparable chain lengths are assumed to be in the same range.

There are no data available for acute inhalation toxicity of alkyl sulfates, alkane sulfonates or α-olefin sulfonates.

In skin irritation tests performed on rabbits in accordance with OECD TG 404, the ca. 30 % aqueous solutions of C_{8-14}- and C_{8-16}, the 90 % solution of C_{12-14}-, and the 60 % solution of $C_{14-18/18=}$-alkyl sulfates were all corrosive. At 25 %, and under occlusive conditions, C_{12}- and C_{12-14}- and at ≥ 5 – 7 % C_{12}-, C_{12-15}-, C_{13-15}- and C_{15-16}–alkyl sulfates were moderate to strong irritants. C_{16-18} ASO_4 Na showed only slight irritation up to concentrations of 31.5 %. The α-olefin sulfonate C_{14-16}=/$OHASO_3$ Na was irritating when tested at a concentration of 40 % according to OECD TG 404. 5 % of an α-olefin sulfonate (C_{14-18}=/$OHASO_3$Na) were only very slightly irritating. Comparative studies investigating skin effects like transepidermal water loss, epidermal electrical conductance, skin swelling, extraction of amino acids and proteins or development of erythema in human volunteers consistently showed a maximum of effects with C_{12} ASO_4Na. 20 % C_{12} ASO_4Na is routinely used as a positive internal control giving borderline irritant reactions in skin irritation studies performed on humans. With C_{12} ASO_4Na being the most irritant alkyl sulfate it can be concluded that in humans 20 % is the threshold concentration for irritative effects of alkyl sulfates in general. When formulated in consumer products, alkyl sulfates are usually used in conjunction

with other surfactants. These mixed surfactant systems form micelles that typically lead to a reduction in irritation potential of the mixture, compared to the irritation potential of the individual ingredients. No data were available with regard to the skin irritation potential of alkane sulfonates. Based on the similar chemical structure they are assumed to exhibit similar skin irritation properties as alkyl sulfates or α-olefin sulfonates of comparable chain lengths.

C_{12}-containing alkyl sulfates (at concentrations ≥ 10 %) were severely irritating to the eyes of rabbits and caused irreversible corneal effects. With increasing alkyl chain length, the irritating potential decreases, and $C_{16-18}ASO_4Na$, at a concentration of 25 %, was only a mild irritant. Concentrated C_{14-16}-α-olefin sulfonates were severely irritating, but caused irreversible effects only if applied as undiluted powder. At concentrations below 10 % mild to moderate, reversible effects were found. No data were available for alkane sulfonates.

Alkyl sulfates and C_{14-18}-α-olefin sulfonates were not skin sensitizers in animal studies performed according to OECD TG 406. In humans, the sensitizing potential of $C_{12}ASO_4$ Na is very low and C_{14-16}-α-olefin sulfonate was not found to have any sensitising potential. No reliable data were available for alkane sulfonates. Based on the similar chemical structure, no sensitization is expected.

For repeated dermal application a "No Observed Adverse Effect Level" (NOAEL) of 400 mg a.i./kg bw/day for systemic effects was found in mice treated twice weekly for 3 or 13 weeks with 0.2 ml of C_{12-15} ASO_4 Na at concentrations of 0, 5, 10, 12.5 or 15 % in water (corresponding to ca. 0, 200, 400, 500, or 600 mg a.i./kg bw/day). At 10 % concentration, epidermal hyperplasia, and at concentrations of ≥ 12.5 % in addition epidermal cytotoxicity (ulceration) was found. Increased water intake and elevated liver, kidney and heart weights were associated with concentrations > 10 %.

After repeated oral application of alkyl sulfates with chain lengths between C_{12} and C_{18}, the liver was the only target organ for systemic toxicity. Adverse effects on this organ included an increase in liver weight, enlargement of liver cells, and elevated levels of liver enzymes. The "Lowest observed adverse effect level" (LOAEL) for liver toxicity (parenchymal hypertrophy and increase in relative liver weight) was found for C_{16-18} ASO_4 Na in a 13-week dietary study on rats at 230 mg a.i./kg bw/day. The lowest NOAEL in rats was at 55 mg a.i./kg bw/day in a 13-week gavage study with C_{16-18} ASO_4 Na.

NOAELs of about 100 mg a.i./kg bw/day were found for rats in comprehensive oral 6 month- and 2-year studies with C_{14}– and C_{14-16}-α-olefin sulfonates. At 200-250 mg a.i./kg bw/day, a reduction in body weight gain was the only adverse effect in these studies.

No data were available with regard to the repeated dose toxicity of alkane sulfonates. Based on the similarity of metabolic pathways between alkane sulfonates, alkyl sulfates and α-olefin sulfonates, the repeated dose toxicity of alkane sulfonates is expected to be similar with NOAEL and LOAEL values in the same range as for alkyl sulfates and α-olefin sulfonates, i.e. 50 - 100 and 200-250 mg a.i./kg bw/day, respectively, with the liver as potential target organ.

Alkyl sulfates of different chain lengths and with different counter ions were not mutagenic in standard bacterial and mammalian cell systems (only Na salts were tested in the latter) both in the absence and in the presence of metabolic activation. There was also no indication for a genotoxic potential of alkyl sulfates in various *in vivo* studies on mice (micronucleus assay, chromosome aberration test, and dominant lethal assay).

α-Olefin sulfonates were not mutagenic in the Ames test, and did not induce chromosome aberrations *in vitro*. No genotoxicity data were available for alkane sulfonates. Based on the overall

negative results in the genotoxicity assays with alkyl sulfates and α-olefin sulfonates, the absence of structural elements indicating mutagenicity, and the overall database on different types of sulfonates, which were all tested negative in mutagenicity assays, a genotoxic potential of alkane sulfonates is not expected.

Alkyl sulfates were not carcinogenic in good quality feeding studies with male and female Wistar rats fed diets with $C_{12\text{-}15}$ ASO_4 Na for two years (corresponding to doses of up to 1125 mg /kg bw/day). No carcinogenicity studies were available for the alkane sulfonates.

α-Olefin sulfonates were not carcinogenic in mice and rats after dermal application, and in rats after oral exposure. Dermal applications in mice were carried out 3 times weekly for 92 weeks with a volume of 0.02 ml of either $C_{14\text{-}16}$ – or $C_{14\text{-}18}$ α-olefin sulfonates at concentrations of 20 or 25 %. Rats were treated twice weekly for 104 weeks with a 10 % solution of $C_{14\text{-}16}$=/$OHASO_3$ Na. In the oral study, Sprague-Dawley rats were dosed with up to 259 mg $C_{14\text{-}16}$=/$OHASO_3$ Na/kg bw/day.

No fertility studies were performed with alkyl sulfates and alkane sulfonates. Oral dosing of male mice with C_{12} ASO_4 Na (1 % over 2 or 0.1 % over 6 weeks) caused no adverse effects on epididymal spermatozoa, and a NOAEL for male fertility was derived at 1000 mg a.i./kg bw/day in an earlier SIDS document for sodium dodecyl sulfate. No indication for adverse effects on reproductive organs was found in various oral studies with different alkyl sulfates. For the α-olefin sulfonates a modern two generation reproductive toxicity study in male and female CD rats was performed with a mixture of C_{14}:C_{16}:C_{18} blend (1:1:1 ratio) of α-olefin sulfonate, Mg salt. Two batches with an active ingredient content of ca. 95 % were used and the animals were continuously dosed with 0, 1250, 2500 or 5000 ppm (corresponding to about 1040 mg a.i./kg bw/day) in the diet with a protocol comparable to OECD TG 416. The animals showed no adverse effects up to and including the highest test concentration of 5000 ppm.

The developmental toxicity of various alkyl sulfates (C_{12} ASO_4 Na, $C_{12\text{-}14}$ ASO_4 Na, $C_{12\text{-}15}$ ASO_4, $C_{13\text{-}15}$ ASO_4 Na, $C_{15\text{-}16}$ AS Na, $C_{16\text{-}18}$ ASO_4 Na) was tested on rats, rabbits and mice. Effects on litter parameters were restricted to doses that caused significant maternal toxicity (anorexia, weight loss, and death at doses between 300 and 500 mg a.i./kg bw for rats and at 300 mg a.i./kg bw/day for mice and rabbits), the principal effects being higher fetal loss and increased incidences of total litter losses. The incidences of malformations and visceral and skeletal anomalies were unaffected apart from a higher incidence of delayed ossification or skeletal variation in mice at ≥ 500 mg a.i./kg bw/day indicative of a delayed development. The lowest reliable NOAEL for maternal toxicity was about 200 mg a.i./kg bw/day in rats, while the lowest NOAELs in offspring were 250 mg a.i./kg bw/day in rats and 300 mg a.i./kg bw/day for mice and rabbits.

For the α-olefin sulfonates no adverse effects were reported in rats (dams and offspring) dosed with up to 600 mg a.i./kg bw/day of $C_{14\text{-}16}$=/$OHASO_3$ Na during days 6-15 of pregnancy, i.e. the NOAEL was 600 mg a.i./kg bw/day both for maternal and developmental toxicity. From a parallel study with mice and rabbits no clear NOAEL can be derived due to an unusual spreading of the applied doses (0, 0.2, 2, 300 and 600 mg a.i./kg bw/day). At 2 mg a.i./kg bw/day no adverse effects were found, while at 300 mg a.i./kg bw/day adverse effects both in dams and offspring were observed.

No data were available for the reproductive and developmental toxicity of alkane sulfonates. Based on the available data, the similar toxicokinetic properties and a comparable metabolism of the alkyl sulfates and alkane sulfonates, alkane sulfonates are not considered to be developmental toxicants.

Although the database for category members with $C < 12$ is limited, the available data are indicating no risk as the substances have comparable toxicokinetic properties and metabolic

pathways. In addition, longer-term studies gave no indication for adverse effects on reproductive organs with different alkyl sulphates.

4 HAZARDS TO THE ENVIRONMENT

4.1 Aquatic Effects

A large number of aquatic toxicity studies have been performed on chemicals from the **AS** and **AOS** family containing single-species acute and long-term data for a variety of different organisms. Particularly for the alkyl sulfates the data basis is rich and well documented with tests conducted on individual homologues as well as on mixtures with different chain length distributions in the range of C_8-C_{18}. An overview on the available environmental toxicity tests performed with alkyl sulfates and sulfonates is presented in Annex IV. In the following only a selection of results is discussed to illustrate specific aspects, like the influence of alkyl chain length or counterions. Main criteria for choosing specific studies were: representativeness for chain length distribution, variety of species from relevant taxonomic groups and trophic levels, and reliability of results.

The toxicity of substances of the ANS category is dependent on a number of parameters: concentration losses during the test period, water hardness, water quality, length of the alkyl chain, and the counter-ion. Despite all these variables, aquatic toxicity results are surprisingly uniform. As will become evident from the findings discussed below, only the chain length influences toxicity in a regular pattern.

Stability of test solutions

Due to their ready biodegradability potential the test substances may degrade in aquatic toxicity tests during exposure, when the test is carried out in a non-sterile medium. In addition, concentration losses can occur due to adsorption of the test substance onto surfaces of the test containers or other parts of the equipment, or by precipitation of the Ca-salts because of their reduced solubility. Results of measurements in static tests reveal excessive loss of the parent material within a few days. Therefore, tests with analytical verification of the test substance concentration or semistatic tests with a short renewal period are preferably used for the aquatic hazard assessment.

Problems occur in tests at concentrations above the CMC when parts of the test substance are present as micelles. The size of micelles may be dependent on the applied procedure for preparation of the test solutions. Contradicting results (see below) in some tests at chain lengths above about C_{15} indicate that the bioavailability of the test substance may vary significantly, particularly for higher homologues.

Mode of action

A theoretical study on the importance of interfacial properties of surfactants on their environmental effects was published by Rosen et al. (1999, 2001). The aquatic toxicity of several anionic and nonionic surfactants (e.g. alkyl sulfates and alkane sulfonates) was explained primarily by the affinity for, and the relative ease with which the surfactant can enter cell membranes. A linear correlation was found between rotifer (*Brachionus calyciflorus*) toxicity and properties like standard free energies and minimum cross sectional areas at the air/solution and the solid/liquid interface. This supports the hypothesis that toxicity of surfactants is determined both by adsorption on biological membranes and cell membrane penetration. Further studies were carried out with green algae *(Pseudokirchneriella subcapitata*, formerly *Selenastrum capricornutum*) and fish (*Pimephales promelas* and *Ictalurus punctatus*) (Rosen et al., 2001). Ecotoxicity was found to be

highly correlated with interfacial activity. Sorption to cell membranes is a critical parameter for predicting and understanding of ecotoxic effects. Once the surfactant has entered the cell membrane, its presence there is believed to interfere with membrane-dependent life processes such as energy metabolism and transport of nutrients and oxygen across the membrane. The surfactants in this category do not have reactive groups that can cause toxicity by reacting chemically with macromolecules. Rather, their toxicity is due to physical/chemical interactions with cell membranes. At low concentrations, these interactions result in the type of generalized toxicity, defined as a "non-specific and reversible disturbance of the functioning of the membrane, caused by accumulation of the pollutants in the hydrophobic phases within the organism". At high concentrations, the disruption of cell membranes results in "irritation" (Van Wezel and Opperhuizen, 1995). Both the nature of the hydrophobe (the alkyl chain) and the nature of the hydrophilic head group, in other words the factors which together define the interfacial properties of the surfactant - play a role in this (Rosen et al., 1999). The hydrophobe determines the ease with which the surfactant will insert itself into the bilayer and the amount of disturbance due to hydrophobic interactions it can cause once it is in place. The observed pattern of increasing toxicity with increasing alkyl chain length - until a point is reached where water solubility becomes the limiting factor - is typical for the ecotoxicity of surfactants in general. The hydrophilic head group contributes to toxicity as a determinant of the surfactant properties of the molecule and, once it has penetrated the lipid bilayer, by disrupting certain membrane-associated functions by altering the local electrostatic environment. For the same hydrophobe, N-containing surfactants (amines and quaternary ammonium compounds) are the most toxic, followed by the nonionic surfactants. The anionic surfactants are the least toxic (Versteeg et al., 1997).

Influence of water hardness

The influence of water hardness to the toxicity of $C_{12}ASO_4$ Na to *Daphnia magna* was examined by Persoone et al. (1989). In a static test over 24 h, 16 combinations of temperature (7, 14, 21, 28 °C) and water hardness (80, 320, 560, 800 mg/l $CaCO_3$) were assayed. At constant temperatures, a 1.3 to 4-fold increase in toxicity was noted between the high and low water hardness levels. At 21 °C (the temperature recommended by the OECD guideline) the EC_{50} values were 9.6 mg/l at 80 mg/l $CaCO_3$ and 39 mg/l at 800 mg/l $CaCO_3$.

However, in a study by Yoshioka, Ogino, and Mori (1995) the toxicity of C_{14-18} AOS to *Oryzias latipes* and *D. magna* increased with increasing water hardness. The LC_{50} values for *O. latipes* were 1.2, 0.5, 0.7 mg/l at 26, 70, 200 mg/l $CaCO_3$ respectively. The 24-h EC_{50} values for *D. magna* ranged from 19.2 mg/l at 26 mg/l $CaCO_3$ to 7.1 mg/l at 367 mg/l $CaCO_3$.

Influence of the alkyl chain length

As demonstrated in several studies, the length of the alkyl chain is the most important factor influencing the ecotoxicity of the ANS category. This is possibly due to the reasons summarized under 'mode of action'. Representative tests are described in the following sections.

Influence of the counter-ion

Although most of the category members are sodium salts, a number of test results with counter-ions other than Na^+ are available. In the following table, toxicity data from alkyl sulfate salts (for references cf. Annex IV) are compared with data for the respective cations. The latter data (not validated) are taken from the IUCLID Year 2000 edition of the European Commission (EC, 2000a - d) (see Table 4-1). Several of the counter-ions have also been assessed in the OECD HPV Programme: triethanolamine (CAS 102-71-6), the ammonia category (CAS 7664-41-7; 1336-21-6; 7783-18-8; 12593-60-1) and ammonium salts, like ammonium sulfate (CAS 7783-20-2), chloride (CAS 12125-02-9) and bicarbonate (CAS 1066-33-7).

Table 4-1: Influence of the counter ion on acute toxicity

Alkyl chain	**CAS No**	**Counter-ion**	**Fish** LC_{50} **[mg/l]**		***Daphnia magna*** EC_{50} **[mg/l]**	
C_{12-14}	**85586-07-8**	**Na**	**3.6**	***O. mykiss*, 96 h, semistatic, nominal conc.**	**2.8**	**48 h, static, nominal conc.**
	90583-23-6	Mg	7.9	*Danio rerio*, 96 h, semistatic, nominal conc.		
	90583-16-7	MEA	3.4 / 4.8	*Danio rerio*, 96 h, semistatic, nominal conc.	14.7	24 h, static, nominal conc.
	90583-18-9	**TEA**	**9.2**	***Leuciscus idus*, 48 h, static, nominal conc.**	**38**	**48 h, static, nominal conc.**
C_{8-14}	85665-45-8	TEA	8.9	*Leuciscus idus*, 48 h, static, nominal conc.		
	90583-10-1	NH_4	5.3	*Danio rerio*, 96 h, semistatic, measured conc.	23	24 h, static, nominal conc.
	90583-19-0	Li	7.3	*Leuciscus idus*, 48 h, static, nominal conc.		
C_{12-18}	**68955-19-1**	**Na**	**9.3**	***Leuciscus idus*, 48 h, static, nominal conc.**		
	90583-13-4	NH_4	2.8	*Danio rerio*, 96 h, semistatic, measured conc.		
Monoethanolamine	141-43-5	MEA	65 - > 5 000		65 - 140	
Triethanolamine	102-71-6	TEA	450 - 11 800		1 390 - 2 038	
Ammonium chloride	12125-02-9	NH_4	2.83 - 650		161	
Magnesium chloride	7786-30-3	Mg	7 700 - 20 000		1 400 - 3 699	

Bold: HPV chemical

The data clearly demonstrate that the toxicity of alkyl sulfate of comparable chain length is not affected by the counter-ion, i.e. toxicity is mainly determined by the surfactant anion.

Toxicity to fish

Mode of action

The mode of action has been examined mostly in relation to its effects on fish gills. Tomiyama (1975) observed significant absorption of **AOS** in the gills of goldfish, while none of the surfactant was found in the alimentary canal. Gafa (1974) found that toxicity could be correlated with surface tension only within classes of chemicals. In an examination of **AOS, alkyl sulfates**, and other surfactants, he postulated that a critical gills–solution interfacial tension exists for each type of fish below which absorption of oxygen by the gills is greatly hindered. The concentration-effect relationship is very steep for most of the AS, the margin in the concentrations at which the fishes are all alive or all dead is very small. The concentration- effect relationships for AOS seem to be similar but only few data are available to support the assumption.

Alkyl sulfates

Acute tests

For acute toxicity to fish a broad database of reliable studies using 13 different species is available, covering a variety of both freshwater and marine species. In this section the most representative studies are discussed, further results are summarized in Annex IV Table IV-1.

Kikuchi and Wakabayashi (1984) studied the influence of the carbon chain length on *Oryzias latipes*. The fish were exposed to three different alkyl sulfates in a semistatic system for 48 h, the medium was renewed every 12 h. In a former study, a similar test on *Oryzias latipes* had been conducted (Kikuchi et al., 1976). In addition, effects of alkyl sulfates on the survival of *Cyprinus carpio* prelarvae and the hatching of eggs were tested. The results are summarized in Table 4-2:

Table 4-2: Acute toxicity of alkyl sulfates to *Oryzias latipes* and *Cyprinus carpio* prelarva

CAS No.	**Chain Length**	***Oryzias latipes* 48 h-LC_{50} [mg/l] Kikuchi and Wakabayashi (1984)**	***Oryzias latipes* 48 h-LC_{50} [mg/l] Kikuchi et al. (1976)**	***Cyprinus carpio* prelarva 48 h-LC_{50} [mg/l] Kikuchi et al. (1976)**	***Cyprinus carpio* eggs 96 h-EC_{50} [mg/l] Kikuchi et al. (1976)**
		nominal	measured	measured	measured
142-87-0	**C_{10}**			**13**	
151-21-3	**C_{12}**	**46**	**51**	**13**	**18**
1191-50-0	C_{14}	2.5	5.9 *	5.0	2.9
1120-01-0	C_{16}	0.61	0.50	0.69	> 1.6

Bold: HPV chemical *) 24 h-LC_{50} (48 h-LC_{50} not available)

Acute toxicity of single chain length AS to *Leuciscus idus* has been tested by one laboratory in independent tests but using identical test protocols. All tests were performed following DIN

38412/15 (comparable to OECD TG 203) in a static system and identical media (values refer to nominal test substance concentrations). Like for the tests performed in parallel a clear dependence of toxicity on chain length could be observed. The results are summarized in Table 4-3:

Table 4-3: Acute toxicity of alkyl sulfates to *Leuciscus idus* (values refer to nominal test substance concentrations)

CAS No.	Chain length	48 h-LC_{50} [mg/l]	Reference	Reliability
142-31-4	**C_8**	**172**	**Cognis (2001a)**	**2**
151-21-3	**C_{12}**	**25**	**Henkel KGaA (1999b)**	**4, insufficient documentation**
3026-63-9	C_{13}	2.1	Cognis (2006a)	2
1191-50-0	C_{14}	3.2	Cognis (2001c)	2
13393-71-0	C_{15}	15	Cognis (2006c)	2
1120-01-0	C_{16}	> 250	Cognis (2001d)	2
1120-04-3	C_{18}	> 270	Cognis (2001f)	2

Bold: HPV chemical

The results of acute toxicity to fish reveal that AS of chain lengths C_8 to C_{12} seem to have low to moderate toxicity. Homologues C_{13} to C_{15} exhibit toxicities between 1 to approx. 10 mg/l in the available studies. These observations are independent of the fish species tested, the counter-ions present or the test conditions; i.e. the results were surprisingly homogenous compared to the various differences in the individual test designs. In view of the rapid biodegradation of AS, one would expect semistatic and particularly flow-through tests to give significantly higher toxicity values because a constant test substance concentration is ensured more reliably. However, observed toxicity is not significantly higher than in static tests for the lower C-chains up to C_{12}. One possible explanation would be that the actual concentration of test substance was maintained long enough to exert toxic effects and a longer or constant exposure like under semistatic or flow-through conditions would not significantly enhance toxicity. This conclusion is corroborated by subchronic tests with C_{12} ASO_4 Na and $C_{16\text{-}18}$ ASO_4, which yield NOECs between 1 and 10 mg/l (see below).

However, the findings from tests with AS of chain lengths of 16 and higher are inconsistent. While the toxicity to *Oryzias latipes* and *Cyprinus carpio* prelarva increased from C_{14} to C_{16}, decreasing toxicity to *Leuciscus idus* was found in the range of C_{15} to C_{18} (see Tables 4-2 and 4-3). The difference in the toxicity of C_{15} to C_{18} can be explained by variable bioavailability as a consequence of reduced water solubility. All tests were performed at concentrations above the CMC. The sizes of micelles might also influence the toxicity, but no information about procedure for preparation of the test solutions is available.

Long-term tests

Valid tests on subchronic toxicity to 6 fish species are available for the compounds $C_{12}ASO_4Na$ and

$C_{16-18}ASO_4Na$. A chronic early life stage test has been performed with $C_{14-15}ASO_4Na$. All studies were conducted under semistatic or flow through conditions, ensuring the stability of the test solutions. The key results are summarized in Table 4-4.

Table 4-4: Long-term toxicity of alkyl sulfates, sodium salts to fish

Chain length	Test type	Result*)	Reference
Subchronic toxicity studies			
C_{12} **CAS No. 151-21-3**	**Larval test** ***Pimephales promelas*** **Semistatic**	**7 d-NOEC = 2.3 - 4.6 mg/l** **7 d-LOEC = 4.6 - 9.2 mg/l** **(survival, dry weight)** **(6 tests)**	**Pickering (1988)**
	Embryo-larval test ***Pimephales promela)*** **Semistatic, 6 tests**	**8 d-NOEC = 2.3 - 4.6 mg/l** **8 d-LOEC = 4.6 - 9.2 mg/l** **(survival)** **8 d-LC_{50} = 4.8 - 5.9 mg/l**	**Pickering (1988)**
	Juvenile test ***Oncorynchus mykiss*** **Flow-through**	**10 d-LC_{50} = 2.85 mg/l **)**	**Fogels and Sprague (1977)**
	Juvenile test ***Danio rerio*** **Flow-through**	**10 d-LC_{50} = 7.97 mg/l **)**	**Fogels and Sprague (1977)**
	Juvenile test ***Jordanella floridae*** **Flow-through**	**10 d-LC_{50} = 6.9 mg/l **)**	**Fogels and Sprague (1977)**
	Larval test ***Cyprinodon variegatus*** **Semistatic, saltwater**	**7 d-LC_{50} = 2.9 mg/l**	**Morrison et al. (1989)**
	Larval test ***Menidia beryllina*** **Semistatic, saltwater**	**7 d-LC_{50} = 1.8 mg/l**	**Morrison et al. (1989)**
	Larval test ***Pimephales promelas*** **Flow-through**	**42 d-NOEC > 1.36 mg/l** **(mortality, weight)**	**Belanger, Rupe, and Bausch (1995)**
C_{16-18} **CAS No. 68955-20-4**	**(*Danio rerio*)** **Semistatic**	**14 d-NOEC = 1.65 mg/l** **14 d-LOEC = 5.5 mg/l** **(mortality)** **14 d-NOEC = 16.5 mg/l** **(sublethal effects)**	**Cognis (2001m)**

Chronic toxicity studies			
C_{14-15} CAS No. 91648-54-3	Early Life Stage Test *Pimephales promelas* Flow-through	34 d-NOEC = 0.11 mg/l 34 d-LOEC = 0.35 mg/l (survival of larvae)	Procter and Gamble (1987)

Bold: HPV chemical

*) all values refer to nominal test substance concentrations, except for Belanger, Rupe, and Bausch (1995) and Procter and Gamble (1987) which report measured concentrations.

**) the tests were conducted in very hard water (350 - 375 mg/l $CaCO_3$) outside of the range recommended by the OECD Guideline (10 - 250 mg/l $CaCO_3$). Therefore, toxicity is probably decreased

The lowest effect values were obtained from the chronic early life stage test on *Pimephales promelas* (Procter and Gamble, 1987). The organisms were exposed for 34 days in a flow-through system to 6 concentrations of a technical product containing C_{14} and C_{15} alkylsulfate. Observations were made on survival of embryos at hatch and survival and growth of larvae after 30 days post-hatch exposure. The most sensitive endpoint was found to be larval survival. Based on analytical measurements of the test substance, the NOEC was calculated to be 0.11 mg/l and the LOEC to be 0.35 mg/l.

Alkane sulfonates

Experimental test results are not available.

α-Olefin sulfonates

Acute tests

For acute toxicity to fish 15 reliable studies are available for 6 different species (cf. Annex IV Table IV-1).

The influence of the carbon chain length can be established by comparing effect values obtained with test substances of different chain length. The tests on *Leuciscus idus* were conducted in the same laboratory under identical conditions. All tests were performed following the DIN 38412/15, which is comparable to OECD TG 203 in a static system and identical media (Cognis, 2001r, s, u). Tests on *Oryzias latipes* were conducted according to the Japanese industrial standard JIS K 0102 (Lion Co., 1972a, b; Kikuchi and Wakabayashi, 1984). Reiff et al. (1979) tested *Rasbora heteromorpha, Salmo trutta*, and *Idus idus* in a static or semistatic system over 96 h. The toxicity to *Danio rerio* was determined in a static test following OECD TG 203 (Kao Co., 1992).

Table 4-5: Acute toxicity of α-olefin sulfonates to fish (all values refer to nominal concentrations)

CAS No.	**Chain length**	***Leuciscus idus* 48 h-LC_{50} [mg/l]**	***Oryzias latipes* 48 h-LC_{50} [mg/l]**	***Rasbora heteromorpha* 96 h-LC_{50} [mg/l]**	***Salmo trutta* 96 h-LC_{50} [mg/l]**	***Idus idus* 96 h-LC_{50} [mg/l]**	***Danio rerio* 96 h-LC_{50} [mg/l]**
30965-85-6	C_{12}	61 [1]					
93686-14-7	**C_{14}**		**20** [4]				
11067-19-9	C_{16}	2.3 [2]					
68439-57-6	**C_{14-16}**			**3.3** [8]	**2.5 - 5.0** [8]	**3.4 / 4.9** [8] ****)**	**2.6** [9]
863609-89-6	**C_{14-18}**		**0.5 - 1.2*** [5] (depending on water hardness) **/1.4** [6]**/ 1.8** [7]				
91722-28-0	C_{16-18}	1.2 [3]	0.81 [7]	0.5 [8]	0.5 [8]	0.9 [8] **)	

Bold: HPV chemical
*) 96 h-LC_{50}
*) the tests were conducted in very hard water (268 mg/l $CaCO_3$) outside of the range recommended by the OECD Guideline (10 - 250 mg/l $CaCO_3$). Therefore, toxicity is probably decreased.
References and test type: 1) Cognis 2001r, static; 2) Cognis 2001s, static; 3) Cognis 2001u, static; 4) Lion Corp. 1973, static; 5) Yoshioka et al. 1995, semistatic, 24 h renewal; 6) Lion Corp. 1972, static; 7) Kikuchi & Wakabayashi 1984, semistatic, 24 h renewal; 8) Reiff et al. 1979, semistatic; 9) Kao Corp. 1992, static

The results reveal that the acute fish toxicity of AOS increases with chain length. The observations proved to be independent from the fish species tested.

Long-term tests

The influence of sodium C_{11-14} olefin sulfonate, which is included in the SIDS Dossier for C_{12-14} =/$OHASO_3$ Na (CAS 85536-12-5) on early ontogenetic stages of the loach *Misgurnus fossilis* and the trout *Oncorhynchus mykiss* was studied in several experiments by Lesyuk et al. (1983). Eggs of loach were tested for fertilization in experimental solutions. Embryos of loach were exposed until hatching (exposure time not reported in the study) and posthatch survival of prolarvae was tested for 12 days past hatching. Fertilized eggs of trout were exposed for 35 to 40 days until hatching. In another test, prolarvae and fingerlings of trout were each exposed for 25 days. The tests solutions were renewed daily. It was observed that mortality of the loach embryos began in the gastrulation stage and during organogenesis, whereas mortality of the trout embryos took place before hatching and (slightly less) before formation of the vascular system. The most sensitive observed endpoint of *M. fossilis* was hatching of the embryos, with a NOEC of

1.70 mg/l. Trout embryos and larvae were more resistant to the test substance than fingerlings, the NOEC for the latter was determined to be 1.70 mg/l.

There are no chronic data available for fish toxicity of AOS.

Conclusion

In the available studies on acute effects of **AS** and **AOS** on fish, toxicity increases with increasing chain length. This has been demonstrated in comparable experiments where **AS** of increasing chain length have been tested under identical conditions. Several studies with **AOS** support this finding. Toxicity (LC_{50}) of C_8 ASO_4 was found to be > 100 mg/l. The watershed is at C_{12}, with some publications reporting LC_{50} values between 13 and 70 mg/l whereas the majority of studies report values in the range of 1 - 10 mg/l. For C_{14} the LC_{50} is generally in the range of 1 - 10 mg/l. At C_{16} and higher the picture becomes inconsistent with toxicities of >100 as well as <1, possibly due to variable bioavailability as a consequence of reduced water solubility.

Available long-term tests with alkyl sulfates give NOECs in the range of the acute LC_{50} values: >1.36 - 4.6 mg/l. The NOEC for chronic fish toxicity (Early Life Stage test) of C_{14-15} ASO_4 Na was 0.11 mg/l.

Available **AOS** LC_{50} (48 h) data determined for C_{12} and C_{14} are (almost like for AS) 20 and 61 mg/l. **AOS** seem to be more toxic than AS at higher chain lengths (C_{16} and longer) with LC_{50} (48 - 96 h) values between 0.5 and 1.8 mg/l. In contrast to AS, the toxicity of **AOS** does not decrease at higher chain lengths.

In a long-term test with sodium C_{11-C14} olefin sulfonate as test substance, NOECs of 1.70 mg/l were determined for early ontogenetic stages of the loach *Misgurnus fossilis* and the trout *Oncorhynchus mykiss*.

No data are available on the fish toxicity of **alkane sulfonates**. Data for respective alkyl sulfate chain lengths can be used to describe their toxicity.

Toxicity to aquatic invertebrates

Alkyl sulfates

Acute tests

A broad database of reliable studies for acute and chronic invertebrate toxicity is available, covering a range of freshwater, marine, and estuary organisms. The results are summarized in Annex IV Tables IV-2 and IV-5.

Various authors have determined the effect of alkyl chain length on toxicity to invertebrates in comparable tests. A clear correlation could be shown: toxicity increases with increasing length of the hydrocarbon chain up to C_{16} and decreases at C_{18}. The flow-through tests on *Ceriodaphnia* performed by Dyer et al. (1997) obviously indicate a higher toxicity compared to the static tests on *Daphnia magna* of Lundahl and Cabridenc (1978) and Sanchez Leal et al. (1991). This most likely reflects constant exposure concentrations compensating any biotic and abiotic losses. In addition, exposure was for 48 h as opposed to 24 h of Lundahl and Cabridenc and Sanchez Leal et al.. According to experience, toxicities still increase between 24 h and 48 h intervals. These results are summarized in Table 4-6.

Table 4-6

: Acute toxicity of alkyl sulfates, sodium salts to *Daphnia magna* and *Ceriodaphnia dubia*

CAS No.	**Chain length**	**Lundahl and Cabridenc (1978)[1)] 24 h-EC_{50} [mg/l], static system *Daphnia magna***	**Sanchez Leal et al. (1991)[1)] 24 h-EC_{50} [mg/l], static system *Daphnia magna***	**Dyer et al. (1997) 48 h-EC_{50} [mg/l], flow-through test *Ceriodaphnia dubia***
		nominal	nominal	Measured
142-31-4	**C_8**	**4350**	**>900**	
1072-15-7	C_9	2300		
142-87-0	**C_{10}**	**800**	**470**	
151-21-3	**C_{12}**	**80**	**25**	**5.55**
3026-63-9	C_{13}	42		
1191-50-0	C_{14}		37	1.58
13393-71-0	C_{15}			0.59
1120-01-0	C_{16}			0.15
1120-04-3	C_{18}			> 0.69 (no mortality)[2)]

Bold: HPV chemical [1)] Because of limited experimental detail, the publications are assigned a reliability score 4 and mentioned here for information purpose only. [2)] highest concentration tested

Acute toxicity of single chain length AS to *Daphnia magna* has been tested by one laboratory in independent tests but using identical test protocols (Table 4-7). All these screening tests were performed following the OECD TG 202 (with some deviations) in a static system and identical media. Like for the tests performed in parallel, a clear dependence of toxicity on chain length could be observed in these cases, too:

Table 4-7

: Acute toxicity results of alkyl sulfates, sodium salts to *Daphnia magna* from the same laboratory (values refer to nominal test substance concentrations)

CAS No.	Chain length	24-EC_{50} [mg/l]	Reference	Reliability score
142-31-4	**C_8**	**>144 (lowest test concentration with effect = 200 mg/l)**	**Cognis (2001b)**	**2**
151-21-3	**C_{12}**	**29**	**Henkel KGaA (1999c)**	**4, insufficient documentation**
3026-63-9	C_{13}	4.2	Cognis (2006b)	2
13393-71-0	C_{15}	70 (with solvent)	Cognis (2006d)	4, use of a solvent control not reported
1120-01-0	C_{16}	> 480	Cognis (2001e)	2
1120-04-3	C_{18}	> 98	Cognis (2001g)	2

Bold: HPV chemical

The results in Tables 4-6 and 4-7 show, that AS of chain lengths C_8 to C_{12} seem to be low to moderately toxic to *Daphnia*. For the C_{13} homologue the EC_{50} was determined to 42 and 4.2 mg/l in two separate studies. The reason for this difference is not known.

The studies available for AS of higher chain lengths were performed in the same laboratory under identical test protocol (Table 4-7) and show lower *Daphnia* toxicity for homologues > C_{15}.

Long-term tests

Dyer et al. (1997) conducted a reproduction toxicity test on *Ceriodaphnia dubia* over 7 days under flow-through conditions. As test substances, alkyl sulfates with a carbon chain length from C_{12} to C_{18} were used. Exposure concentrations were monitored using the MBAS (methylene blue active substances) method which quantifies the total amount of anionic surfactant. The toxicity experiments were conducted below the Krafft point of the Ca-salts, thus no micelles were present in the system. As test medium reconstituted water of moderate hardness (114 - 205 mg/l $CaCO_3$) was used. Results of this study are summarized in Table 4-8.

Table 4-8: Chronic toxicity of alkyl sulfates to *Ceriodaphnia dubia* (Dyer et al., 1997) (endpoint: reproduction) (values refer to measured test substance concentrations)

Chain length	C_{12}	C_{14}	C_{14} (45 %), C_{15} (55 %)	C_{15}	C_{16}	C_{18}
CAS No.	**151-21-3**	1191-50-0	91648-54-3	13393-71-0	1120-01-0	1120-04-3
7 d-NOEC [mg/l]	**0.88**	<0.062	0.081	0.23	0.204	0.602

Relating alkyl chain length with toxicity, a parabolic response curve was observed in this study: toxicity increased with chain length from C_{12} to C_{14} and then decreased up to C_{18}. Precipitate was clearly visible for tests with C_{18} and slightly visible for C_{16} exposure.

A similar toxicity was observed in a study on chronic toxicity to *Daphnia magna* with a technical product containing C_{14} and C_{15}-AS (Procter and Gamble, 1988). The test was conducted in a flow-through system, using fortified well water with a hardness of 160 - 190 mg/l $CaCO_3$ as test medium (hardness during test was 150 - 160 mg/l $CaCO_3$). The exposure concentrations were analytically controlled. For the endpoint reproduction, a 21 d-NOEC of 0.050 mg/l based on measured concentrations is reported.

Further results from long-term tests with invertebrates in either semistatic or flow-through systems are available (Table 4-9). Bode, Ernst, and Arditti (1978) tested the toxicity of alkyl sulfates with a chain length between 10 and 16 on the budding rate of the freshwater polyp *Hydra attenuata*. Belanger, Rupe, and Bausch (1995) tested C_{12} ASO_4 on the clam *Corbicula fluminea* (endpoint: growth), the snail *Goniobasis* sp. (endpoints: mortality, biomass), and the caddisfly *Limnephilus* sp. (endpoints: mortality and emergence). Results on *Hydra attenuata* showed decreasing toxicity with increasing chain length from C_{12} to C_{16}.

Table 4-9: Long-term toxicity of alkyl sulfates on different invertebrates

CAS No.	**Chain length**	***Hydra attenuata* 21 d-NOEC [mg/l] (Bode, Ernst, and Arditti, 1978)**	***Corbicula fluminea* 42 d-NOEC [mg/l] (Belanger, Rupe, and Bausch, 1995)**	***Goniobasis* sp. 56 d-NOEC [mg/l] (Belanger, Rupe, and Bausch, 1995)**	***Limnephilus* sp. 56 d-NOEC [mg/l] (Belanger, Rupe, and Bausch, 1995)**
		Nominal	**measured**	**measured**	**measured**
142-87-0	**C_{10}**	**5.2**			
151-21-3	**C_{12}**	**5.8**	**0.418**	**≥ 1.357**	**0.418**
1191-50-0	C_{14}	63			
1120-01-0	C_{16}	≥ 688			

Bold: HPV chemical

For $C_{12}ASO_4$ Na, a life-cycle bioassay on the rotifer *Brachionus calyciflorus* was conducted in a static system (Versteeg et al., 1997; Procter and Gamble, 1996a). After 48 h of exposure an EC_{20} of 0.77 mg/l based on measured concentrations was determined. For $C_{14}ASO_4$ Na, a 48 h-EC_{20} of 0.29 mg/l based on measured concentrations was determined by the same authors.

Alkane sulfonates

Acute tests

There are 2 studies available on the toxicity of alkane sulfonates with chain lengths between C_8 and C_{14} on *Daphnia magna*. The tests were conducted according to the French test guideline AFNOR T.90310 (1974 and 1983, respectively) (Table 4-10).

Table 4-10: Acute toxicity of alkane sulfonates to *Daphnia magna* (values refer to nominal test substance concentrations)

CAS No.	Chain length	Lundahl and Cabridenc (1978) 24 h-EC_{50} [mg/l] [1)]	Sanchez Leal et al. (1991) 24 h-EC_{50} [mg/l] [1)]
5324-84-5	**C_8**	**3200**	**>900**
13419-61-9	C_{10}	-	350
2386-53-0	C_{12}	220	135
27175-91-3	C_{14}	60	97

Bold: HPV chemical [1)] Because of limited experimental detail, the publications are assigned a reliability score 4 and mentioned here for information purpose only.

The results of both studies indicate clearly an increase of toxicity at chain lengths from C_8 to C_{14}.

Long-term tests

In the life-cycle bioassay to the rotifer *Brachionus calyciflorus,* conducted with $C_{12}ASO_3$ Na as test substance, a 48 h-EC_{20} of 4.5 mg/l based on measured concentrations was determined (Versteeg et al., 1997; Procter and Gamble, 1996a).

α-Olefin sulfonates

Acute tests

There are 5 tests on the acute toxicity to invertebrates (*Daphnia magna* and *Ceriodaphnia dubia*) available. The tests were performed under static or semistatic conditions according to the OECD TG 202. The results indicate that toxicity increases slightly at chain lengths from C_{14} to C_{16}. For C_{14-16} AOS, an EC_{50} (48 h) of 4.5 mg/l was calculated from a test performed with *Ceriodaphnia dubia* (Warne and Schifko, 1999).

Table 4-11: Acute toxicity of α-olefin sulfonates to *Daphnia magna*

CAS No.	Chain length	Duration	EC_{50} [mg/l]	Reference
93686-14-7	**C_{14}**	**48 h**	**14.4 (measured)**	**Lion Co. (2004a)**
11067-19-9	C_{16}	24 h	8.9 (nominal)	Cognis (2001t)
68439-57-6	**C_{14-16}**	**48 h**	**3.48 (nominal)**	**Kao Co. (1993)**
863609-89-6	**C_{14-18}**	**24 h**	**19.2 (nominal) hardness, 26 - 30 mg/l ($CaCO_3$) 12.2 (hardness 97 mg/l ($CaCO_3$) 10.6 (hardness 187 mg/l ($CaCO_3$) 7.1 (hardness 367 mg/l ($CaCO_3$)**	**Yoshioka, Ogino, and Mori (1995)**

Bold: HPV chemical

Long-term tests

The chronic toxicity to *Daphnia magna* was studied with a 21 d reproduction test in a semistatic system using a test medium with high water hardness (Elendt M4 medium, hardness 250 mg/l $CaCO_3$). The test solution was renewed 3 times per week. Analytical control revealed that the test concentration was stable during the exposure period. After 21 d of exposure to C_{14}=/$OHASO_3$ Na, a NOEC (based on measured concentrations) of 6.7 mg/l was obtained (Lion Co., 2004d). The effect concentration is within the range obtained in tests on acute toxicity.

Conclusion

The influence of the chain length of **alkyl sulfates** on the acute toxicity to invertebrates is comparable to fish toxicity results. While the EC_{50} values up to C_{10} were found to be > 100 mg/l, toxicity increases with higher homologues. In chronic tests on *Ceriodaphnia*, toxicity increases up to C_{14} and then decreases at higher chain lengths. Decreasing toxicity was also shown for the freshwater polyp *Hydra attenuata* with chain length increasing from C_{12} to C_{16}.

The acute toxicity of **alkane sulfonates** to *Daphnia magna* is comparable to **AS** in the range between C_8 and C_{10}, while C_{12} and C_{14} are significantly less toxic. Data obtained in chronic (life cycle) assays for C_{12} ASO_3 Na and C_{12} ASO_4 Na with the rotifer *Brachionus calyciflorus* similarly show that alkane sulfonates might be less toxic than AS. C_{16} and C_{18} alkane sulfonates are assumed to exhibit the same toxicity than AS of comparable chain lengths. However, the database for alkyl sulfonates is rather small. The effects of **AOS** to daphnids resulted in EC_{50} values between 3.48 and 19.2 mg/l, indicating a slight increase of toxicity at chain lengths from C_{14} to C_{16}. A comparison with **AS** of the effects to daphnids at chain lengths >14 is not possible because of the contradictory results with AS (see above). The only long-term test available on C_{14}-AOS gave a NOEC of 6.7 mg/l.

Toxicity to algae / aquatic plants

Alkyl sulfates

Several reliable experimental studies are available for alkyl sulfates (cf. Table 4-12 and Annex IV Table IV-3).

Table 4-12

: Toxicity of alkyl sulfates, sodium salts to algae

CAS No.	Chain length	Species	Duration	Effect value [mg/l]	Reference
151-21-3	**C_{12}**	***Desmodesmus subspicatus***	**72 h**	**E_rC_{50} > 120** **E_bC_{50} = 53** **NOEC = 30**	**Henkel KGaA (1994)**
		Pseudokirchneriella subcapitata	**96 h**	**E_rC_{50} = 117** **E_rC_{10} = 12**	**Nyholm and Damgaard (1990)**
68585-47-7	**C_{10-16}**	***Pseudokirchneriella subcapitata***	**72 h**	**EC_{50} = 60** **(cell number)**	**Yamane et al. (1984)**
85586-07-8	**C_{12-14}**	***Desmodesmus subspicatus***	**72 h**	**E_rC_{50} = 27**	**Verge and Moreno (1996)**
68955-19-1	**C_{12-18}**	***Desmodesmus subspicatus***	**96 h**	**E_rC_{50} = 38** **NOEC = 0.9**	**Henkel KGaA (1992g)**
91648-54-3	C_{14-15}	*Pseudokirchneriella subcapitata*	72 h	EC_{50} = 4.6 EC_{10} = 1.6 (cell number)	Procter and Gamble (1986)
		Desmodesmus subspicatus	70 h	E_rC_{50} = 4.9 E_rC_{10} = 1.6 NOEC = 1.0 E_bC_{50} = 4.0 E_bC_{10} = 0.9	Procter and Gamble (1993d)
68955-20-4	**C_{16-18}**	***Desmodesmus subspicatus***	**72 h**	**E_rC_{50} = 34**	**Cognis (2001ee)**

Bold: HPV chemical

Bioassays on growth inhibition of algae are available for C_{12} ASO_4 Na and several technical products (all sodium salts). The available E_rC_{50} range from > 120 mg/l for C_{12} to 4.6 mg/l for C_{14-15}. The results do not allow the prediction of a chain length dependency of algal toxicity because most of the studies were conducted with technical products. However, it seems that algae react less sensitive to alkyl sulfate exposure than fish and invertebrates.

In only 5 of the 14 studies NOEC resp. EC_{10} values have been reported. The lowest effect value obtained from the tests is a NOEC of 0.9 mg/l for growth inhibition of *Desmodesmus subspicatus* (Henkel KgaA, 1992g).

There is one test with an aquatic macrophyte (*Lemna minor*) available. For the most sensitive endpoint root length an EC_{50} of 18 mg/l was calculated (Bishop and Perry, 1979).

Alkane sulfonates

Experimental test results are not available. Data for respective alkyl sulfate chain lengths can be used to describe the toxicity of alkane sulfonates.

α-Olefin sulfonates

Two reliable toxicity tests with C_{14}=/$OHASO_3Na$ and C_{14-18}=/$OHASO_3Na$ using the algae *Pseudokirchneriella subcapitata* are available. The toxicity values of 42.3 mg/l (E_bC_{50}, based on measured concentrations), 81.8 mg/l (E_rC_{50}, based on measured concentrations) (Lion Corp., 2004c) and 45 mg/l (E_rC_{50}, nominal) (Yamane, Okada, and Sudo, 1984), respectively, are in the same range as observed for alkyl sulfates. The limited data indicate that algae might react less sensitive to α-olefin sulfonates exposure than fish and invertebrates.

No data are available on the algae toxicity of the HPV-chemical C_{14-16}AOS.

For C_{14}=/$OHASO_3Na$ 72 h-NOECs of < 5.9 mg/l (biomass) and of 12.8 mg/l (growth rate) were determined based on measured concentrations (Lion Corp., 2004c).

In the study with C_{14-18} (Yamane, Okada, and Sudo, 1984) NOEC, LOEC, or EC_{10} were not reported.

Multispecies Tests

As compared to single-species tests, meso- or microcosm studies involving more than one species are a better approximation to reality and are therefore characterized by a higher predictive value. C_{12} ASO_4Na and C_{14-15} ASO_4 have been investigated by various authors in a number of multispecies tests at ecosystem level.

Belanger et al. (1996) studied the effect of $C_{12}ASO_4Na$ on natural periphyton communities in a flow-through laboratory microcosm system with an exposure duration of 28 d. The typical community species richness ranged from 16 to 22 taxa. Measured endpoints were the change in dissolved oxygen (indicator of whole system production), cell density and biovolume of dominant populations, periphyton dry weight, cell density and biovolume of community, and taxa richness. With respect to cell density and biovolume, one of 12 dominant populations (*Melosira varians*) had a NOEC of 0.055 mg/l, for all other taxa the NOEC was > 0.553 mg/l (highest concentration tested). The NOEC for dissolved oxygen was 0.111 mg/l and for all other examined endpoints > 0.553 mg/l. NOECs were based on measured concentrations.

An extensive experiment which can be divided into several studies was conducted in a P&G experimental stream facility (ESF) which was run with natural river water under outdoor conditions (Belanger, Meiers, and Bausch, 1995; Guckert et al., 1996; McCormick, Belanger, and Cairns, 1997; Belanger et al., 2004). The stream channels were 12 m long and divided into 5 sections. Test substance was constantly added to head boxes via chemical feed tanks. Measured test concentrations were 0.020, 0.061, 0.224, 0.582, 1.586 mg/l, and two control steams. The average hydraulic retention time from the headbox to the tail pool was approximately 3.5 min. In all studies the test substance was monitored and the results are expressed as measured concentrations.

At this facility, Belanger, Meiers, and Bausch (1995) studied the response of $C_{12}ASO_4Na$ on macroinvertebrates. Test organisms were collected from Lower East Fork River: Cobbles were embedded in the river stream bed substrate for 56 days and then transferred to the ESF. Also benthic invertebrates were collected with Hess sampler (surface area 0.083 m^2, depth 10 cm). The invertebrates were allowed to colonize and acclimate to ESF conditions for additional 22 days prior to test start. The test organisms were sampled after 0, 4, and 8 weeks of exposure and were identified to the lowest practical taxon by available taxonomic keys. The measured endpoints were total and population abundance, total and population biomass, relative abundance, taxa richness, Shannon diversity, trophic functional feeding group abundance and biomass, drift rate and density, drift richness and drift Shannon diversity. The total invertebrate density increased with AS

exposure, which was explained by an increase of heterotrophic periphyton biomass at 0.224 - 1.586 mg/l. The total biomass of non-oligochaetes was not affected, but certain groups increased or decreased. Drift density, rate, and diversity were not affected. The experiment resulted in a NOEC of 0.224 mg/l based on increase of total invertebrate density due to increased heterotrophic periphyton biomass.

Guckert (1996) studied the effects of $C_{12}ASO_4$ on microbial stream communities. Cobbles precolonized in river water were placed in the ESF (as described in Belanger, Meiers, and Bausch, 1995). In addition clay tiles were placed to ESF and allowed to colonize until exposure for ca. 4 weeks. The test organisms (photoautotrophic and heterotrophic microorganisms) were sampled after 0, 1, 2, 4, 6, and 8 weeks of exposure. The test substance was rapidly removed by mineralization and to a lower extent by sorption. The turnover time decreased from 10 - 50 h in non-acclimated stream channels to 2 hours at 1 586 mg/l after 8 weeks of exposure. The rapid biodegradation resulted in higher bacterial cell density only at the highest concentration. No effects on photoautrophic activity (measured with ^{14}C-bicarbonate) were observed at any concentration. The heterotrophic activity (measured as rate of ^{3}H amino acid incorporation into cell biomass) was significantly lower at the highest concentration. Protozoan taxa richness increased at the 2 highest concentrations (0.582 and 1 586 mg/l), most likely due to increase in the bacteriovorous protozoa. Therefore, a NOEC for protozoan taxa richness of 0.224 mg/l, for heterotrophic activity of 0.582 mg/l and for autotrophic activity of > 1.59 mg/l, respectively, were obtained.

The response of $C_{12}ASO_4$ exposure to lotic protistan communities was studied by McCormick et al. (1997). Channels were allowed to colonize with protists and other organisms entrained in water entering from the lower east fork of the Little Miami River for 22 days before initial of test substance application. Protozoa were monitored on polyurethane foam substrates. The substrates were introduced into the stream channels two days before test start to assess the effect of the chemical on the maintainance of normal community structure and function in “mature” protist assemblages and at day of test start to assess the effect of the substance on protist recolonization of initially barren substrate. Duplicate substrates were collected after 0, 2, 14, 27, 41, and 55 days (“mature”) and 1, 2, 6, 13, and 20 days (“immature”), respectively. The community respiration was stimulated with increasing concentrations. The oxygen concentration decreased significantly on day 20 (“immature” communities, EC_{20} = 1.412 mg/l) resp. 27 (“mature”, EC_{20} = 0.302 mg/l). The 55 d-EC_{20} for mature communities was 0.289 mg/l. The protozoan species richness increased with test substance concentrations, the 55 d-EC_{20} for “immature” communities was determined to be 0.063 mg/l and the 20 d-EC_{20} for “mature” communities was determined to be 0.098 mg/l. No statistically significant change in diatom species composition was detected in immature assemblages. A statistically significant change in diatom species composition was detected in mature assemblages, which resulted in a 55 d-EC_{20} = 0.345 mg/l. The effect concentrations are based on nominal concentration at the head of each channel.

Belanger et al. (2004) examined the response of invertebrates and periphyton in the P&G experimental stream facility to a technical $C_{14\text{-}15}ASO_4$ product (concentration range 0.057 - 0.419 mg/l, measured). The periphyton function was evaluated via incorporation of radiolabelled bicarbonate and tritiated mixed amino acids. Both parameters were found to be not significantly influenced in concentrations up to 0.419 mg/l. Only three of approximately 264 algal and invertebrate species had population level NOECs of 0.222 mg/l at the end of the 56 d-exposure period. The top algal dominants *Pleurosira leavis* and *Melosira varians* were absent at 0.419 mg/l, while the third most dominant *Navicula symmetrica* was unaffected. Also the abundance of Tubellaria (invertebrate) was significantly reduced at the highest concentration after 56 d.

Conclusions to aquatic Toxicity

Alkyl sulfates

The matrix of data for the aquatic toxicity of alkyl sulfates is rich and well documented. Many mono-species-tests are available on the acute and long-term toxicity to fish, invertebrates, and algae, conducted with single-chain homologues as well as with technical mixtures. The results demonstrate that invertebrates are the most sensitive trophic level, followed by fish and algae.

The aquatic toxicity is influenced by a number of parameters, like stability of the test solution, water hardness, origin of the medium (natural or synthetic). It has been shown that toxicity is fairly independent from the counter-ion. The most important influencing parameter for fish and invertebrates is the chain length of the alkyl group.

The key study for the hazard assessment is the test with *Ceriodaphnia dubia* conducted by Dyer et al. (1997). This study covers a range of alkyl chain lengths from C_{12} to C_{18} for one of the most sensitive invertebrate species, was conducted in a flow-through system, and toxicity values were based on measured test concentrations. Relating chain length with toxicity, a parabolic response of the 7 d-NOEC was observed, with a minimum effect concentration at C_{14}. The increase of toxicity from C_{12} to C_{14} can be explained by increased adsorption on biological membranes, while the decrease from C_{14} to C_{18} was probably caused by the limited water solubility of higher homologues.

Several homologues are not covered by the study of Dyer et al. (1997), therefore their NOECs were estimated:

- For the fractions C_{11} and below and C_{20} and above, the NOEC values for C_{12} and C_{18}, respectively, were taken as a worst case approach.
- For C_{14}, a NOEC could not be determined, the LOEC was found to be 0.062 mg/l (lowest concentration tested). However, a NOEC of 0.081 mg/l was found for the commercial C_{14-15} product (45 : 55 %). The C_{14} NOEC was calculated as follows:

  $[NOEC\ C_{14-15}] = 1 / [45\ \% / [NOEC\ C_{14}] + 55\ \% / [NOEC\ C_{15}]]$

  ⇨ NOEC C_{14} = 0.045 mg/l
- For C_{13} the value was calculated from NOECs for C_{12} and C_{14} assuming an exponential increase of toxicity with chain length:

  ⇨ NOEC C_{12} = 0.88 mg/l log 0.88 = -0.0555

  ⇨ NOEC C_{14} = 0.045 mg/l log 0.045= -1.347

  ⇨ NOEC C_{13} = 10 exp [(-0.0555 - 1.347)/2] = 0.20 mg/l

Experimentally determined and estimated NOECs derived from this study were summarized in Table 4-13.

Table 4-13: Experimentally determined and estimated NOECs (based on measured concentrations) derived from the study of Dyer et al. (1997) for AS with different chain lengths

Chain length	$C_{\leq 11}$	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{18}	$C_{\geq 20}$
NOEC [mg/l]	0.88	0.88	0.20	0.045	0.23	0.204	0.602	0.602

Mesocosm studies are appropriate to predict realistic NOECs, as they cover a broad range of species. However, the available studies of this type do not cover the whole range of chain lengths like the monospecies tests do, although the most toxic alkyl sulfate homologues are covered. For $C_{12}ASO_4Na$ NOEC of 0.055 mg/l was determined for algal periphyton communities in a laboratory microcosm system. In an extensive experiment conducted in an experimental stream facility with $C_{12}ASO_4Na$ as test substance, the NOEC for macroinvertebrates was 0.224 mg/l. In the same experiment, the protozoan species richness increased with test substance concentrations, the 55 d-EC_{20} for "immature" protist communities was determined to be 0.063 mg/l. In the same stream facility with $C_{14/15}ASO_4Na$ as test substance, a 56 d-NOEC of 0.222 mg/l was determined for two algal and one invertebrate species.

Alkane sulfonates

Several tests on *Daphnia magna* and one test with *Brachionus calyciflorus* are available, indicating an increasing toxicity at chain lengths between C_8 and C_{14}. While the effect values for C_8 and C_{10} are comparable to AS, the higher homologues proved to be less toxic. This becomes most evident in the chronic study on *Brachionus calyciflorus* where $C_{12}ASO_3Na$ and $C_{12}ASO_4Na$ have been tested in parallel and a more than 8-fold higher toxicity was determined for the sulfate. Experimental test results on fish and algae are not available.

α-Olefin sulfonates

Several test results on the acute toxicity to fish, invertebrates, and algae are available.

The observed toxicity to fish increases strongly with the alkyl chain length in the range between C_{12} and C_{18} (cf. Table 4.5 and Annex IV Table IV-1). The comparison of the effect values with those of alkyl sulfates with the same alkyl chain length shows an inconsistent picture: While the toxicity of the $C_{12}AOS$ homologue to *Leusiscus idus* is lower by a factor of about 3 compared to the respective alkyl sulfate, the AOS homologues C_{16} and C_{18} are much more toxic.

In a long-term test with sodium C_{11-14} olefin sulfonate as test substance, NOECs of 1.70 mg/l were determined for early ontogenetic stages of both the loach *Misgurnus fossilis* and the trout *Oncorhynchus mykiss*.

In several tests on the acute toxicity to *Daphnia magna* an influence of the carbon chain length in the range between C_{14} and C_{18} could not be observed. The effect values indicate a higher toxicity at C_{16} and above, when compared with AS.

In a test on the chronic toxicity to *Daphnia magna*, a NOEC of 6.7 mg/l for C_{14}=/$OHASO_3Na$ was obtained. The effect concentration is within the range obtained in tests on acute toxicity.

Results of 2 tests on the algae *Pseudokirchneriella subcapitata* indicate that - like for the alkyl sulfates - algae react less sensitive to AOS exposure than fish and invertebrates.

Toxicity to microorganisms

Alkyl sulfates

There are tests according to the German guideline DIN 38412, part 8 (growth inhibition test) on *Pseudomonas putida* available covering alkyl sulfates with alkyl chain lengths of C_{12} and C_{14} (cf. Annex IV Table IV-6). 16 h-NOECs were 272 and 915 mg/l, respectively, based on nominal concentrations.

There are tests on *Pseudomonas putida* following the German guideline DIN 38412, part 27 (respiration inhibition test) available covering alkyl sulfates with an alkyl chain length between C_{12}

and C_{18} (cf. Annex IV Table IV-6). In tendency, the toxicity increased with increasing chain length: while for $C_{12}ASO_4Na$ the 30 min-EC_0 was determined to be 9 050 mg/l (Henkel KgaA, 1999d) (rel. 4, but only available study for this substance), the values for the technical products $C_{12\text{-}18}ASO_4Na$ and $C_{14\text{-}18,\ 18=}ASO_4Na$ were ≥ 3940 and = 300 mg/l, respectively, based on nominal concentrations (Henkel KgaA, 1995, 1993a).

With activated sludge of a municipal sewage treatment plant EC_{50} values of 188 and 135 mg/l (nominally) were obtained for the endpoint respiration inhibition after 30 min and 3 hours of exposure, respectively, to $C_{12}ASO_4Na$ (Dutka, Nyholm, and Petersen, 1983). In a similar test, however using synthetic activated sludge, Dutka and Kwan (1984) determined a 3 h-EC_{50} value of 480 mg/l (nominally) for $C_{12}ASO_4Na$.

Tests on protozoa reveal that these species are more sensitive. The lowest effect value was obtained from a test on *Uronema parduczi* using $C_{12}ASO_4Na$ as test substance, the 20 h-EC_5 was 0.75 mg/l (Bringmann and Kuehn, 1980).

Alkane sulfonates and α-Olefin sulfonates

Experimental test results for microorganisms are not available.

Toxicity to benthic organisms

There are only three valid studies (two static and one semistatic) available on the toxicity of the alkyl sulfate $C_{12}ASO_4Na$ to benthic organisms which were however conducted in seawater without sediment. Toxicity to sediment worms was similar between all three tests. After 48 h of exposure in the semistatic test, Conti (1987) determined for *Arenicola marina* an LC_{50} of 15.2 mg/l (nominally). Experimental test results on benthic organisms in water-sediment systems are not available.

4.2 Terrestrial Effects

There is no valid study on the toxicity to terrestrial organisms available. The only available toxicity data on terrestric organisms were excerpted from insufficiently documented studies (reliability not assignable) to get an indication on possible toxicity on soil organisms.

Toxicity to terrestrial microorganisms

The alkyl sulfate $C_{12}ASO_4Na$ delayed the acid- and iron leaching, caused by *Thiobacillus* and other iron oxidizing bacteria, and decreased the bacteria count in the test soils (Kleinmann, Crerar, and Pacelli, 1981; Olem, Bell, and Longaker, 1983; Watzlaff, 1988). The acidity and iron content in the drainage of coal refuse piles was 80-fold lower at 2 - 12 mg/l (concentration measured in drainage, no further information) compared to the control after 100 d (Kleinmann, Crerar, and Pacelli, 1981). Watzlaff (1988) observed inhibition of iron-oxidizing bacteria and reduction in acidity, sulfate and metal concentrations in the leachate of unweathered mining material in 60 mg/kg and 600 mg/kg treatments. Bacterial numbers and acidity were reduced in leachate of coal columns in 50 mg/l solution (corresponding to 10 mg/kg coal) (Olem, Bell, and Longaker, 1983).

Toxicity to terrestrial plants

The lowest observed effect values for toxicity of $C_{12}ASO_4Na$ on terrestrial plant seedlings are the 48 h-EC_{50} values (inhibition of root growth) of 361 mg/l for chick peas, *Cicer arietinum* and 384 mg/l for white lupine, *Lupinus albus* (Schmidt, 1988).

$C_{12}ASO_4Na$ was observed to have irreversible inhibitory effects on mitosis and growth in the primary root of seedlings of *Pisum sativum* at a concentration of 1 100 mg/l (0.1 % v/v) after a 4 h exposure period (Nethery, 1967).

In a ring test according to guideline 79/831/EEC (1986) with $C_{16-18}ASO_4Na$, the lowest NOEC of 300 mg/kg were observed for raddish (*Raphanus sativus*) and beet (*Brassica rapa*) after 14 d. A growth promotion was discernible below the toxic concentrations (Henkel KgaA, 1995b; Steber, Gode, and Guhl, 1988).

Toxicity to terrestrial invertebrates

For $C_{16-18}ASO_4Na$, the highest tested concentration of 1 000 mg/kg soil (dw) was non-toxic for the earthworm *Eisenia fetida* in a 14-day acute toxicity test (BBA-guideline) with artificial soil (NOEC > 1 000 mg/kg; Steber, Gode, and Guhl, 1988).

Alkane sulfonates and α-Olefin sulfonates

Experimental test results for terrestrial organims are not available.

Conclusion

The available toxicity data on terrestric organisms were excerpted from insufficiently documented studies. However, the data indicate that toxic effects on soil organisms might only be expected at high concentrations for alkyl sulfates. Toxicity of alkane sulfonates and α-olefin sulfonates can not be assessed because test results for terrestrial organims are not available.

4.3 Other Environmental Effects

No data available.

4.4 Initial Assessment for the Environment

Environmental Behavior

For sodium salts of alkyl sulfates, measured melting points are in the range of 181 °C (C_8) to 193 °C (C_{16}). Calculated melting points are in the range of 232 °C (C_8) to 286 °C (C_{16}).

Measured melting points for alkane sulfonates, alkene sulfonates, and hydroxy alkane sulfonates are not available. Calculated melting points are in the ranges of 227 - 281 °C (C_{8-18} alkane sulfonates), 250 - 283 °C (C_{12-18} alkene sulfonates), and 274 - 296 °C (C_{14-18} hydroxy alkane sulfonates).

As ionic substances, all members of this category have extremely low vapor pressures. Calculated values are in the ranges 10^{-11} to 10^{-15} hPa (C_{8-18} alkyl sulfates), $4.3 \cdot 10^{-11}$ to $9 \cdot 10^{-15}$ hPa (C_{8-18} alkane sulfonates),
$2.1 \cdot 10^{-13}$ to $6.9 \cdot 10^{-15}$ hPa (C_{14-18} alkene sulfonates), and $3.3 \cdot 10^{-17}$ to $5.8 \cdot 10^{-19}$ hPa (C_{14-18} hydroxy alkane sulfonates). Therefore, they decompose before reaching their theoretical boiling points.

Measured water solubilities are available only for alkyl sulfates; they are in the range 196 000 mg/l (C_{12}) to 300 mg/l (C_{16}) and by factors of 50 to 300 higher than calculated values (C_{12}: 617 mg/l, C_{16}: 5 mg/l).

As surfactants have a tendency to concentrate at hydrophilic/hydrophobic boundaries rather than to equilibrate between phases K_{OW} is not a good descriptor of surfactant hydrophobicity and only of limited predictive value for the partitioning of these compounds in the environment.

All calculated physico-chemical properties of surfactants should be treated with caution, because the estimation models do not take into account surfactant properties and are not suitable for ionic compounds.

Deduced from physico-chemical and surfactancy properties the target compartment for the substances of this category is the hydrosphere. Based on the ionic structure partitioning into the atmosphere can be excluded. In water, the compounds are stable to hydrolysis under environmental conditions.

Taking into account the low BCF factors (≤ 73) up to C_{16} that were determined for **alkyl sulfates**, any significant bioaccumulation is not expected.

Soil sorption increases with chain length. Strong sorption on soils would be expected for chain length 14 upwards. However, sediment measurements did reveal only low concentrations for C_{12} and C_{14} **alkyl sulfates** (3.5 – 21 µg/kg dw), indicating that the absorbed material is amenable to biodegradation thus preventing significant accumulation in sediment. Under certain conditions of reduced moisture in soil, i.e. in arid or semi-arid regions, accumulation in soil cannot be excluded. In addition, monitoring studies show that concentrations in surface waters are generally low (typically < 5 µg/l and maximally 10 µg/l).

Significant biodegradation of **alkyl sulfates** in the raw sewage, i.e. in the sewer system before reaching the WWTPs is very likely. The substances of this category are quantitatively removed in WWTP's, mainly by biodegradation. Because of the anaerobic degradation of alkyl sulfates in sewage sludge, exposure of agricultural soils due to application of sludge as fertilizer is not expected. However, for **alkane sulfonates** and **α-olefin sulfonates** this exposure pathway cannot be excluded due to their recalcitrant or limited anaerobic degradability.

Environmental Effects

The aquatic toxicity is influenced by a number of parameters, the length of the alkyl chain being most important. The pH and temperature of water bodies can affect the EC/LC_{50} values for compounds that contain ammonium ions.

The most sensitive trophic level in tests on the toxicity of **alkyl sulfates** were invertebrates, followed by fish. Algae proved to be less sensitive.The key study for the aquatic hazard assessment is a chronic test on *Ceriodaphnia dubia*, which covers a range of the alkyl chain length from C_{12} to C_{18}. A parabolic response was observed with the C_{14} chain length being the most toxic (NOEC = 0.045 mg/l).

There are a number of valid acute toxicity data for many species from all trophic levels available. Taking the data from the whole subcategory into account chronic and subchronic data for all 3 trophic levels are available.

For **alkane sulfonates**, the acute toxicity on *Daphnia magna* has been determined for chain length C_8 - C_{14}. Results were comparable to **AS** in the range between C_8 and C_{10}, while C_{12} and C_{14} are significantly less toxic. Chronic data obtained for $C_{12}ASO_3Na$ and $C_{12}ASO_4Na$ with the rotifer *Brachionus calyciflorus* similarly show that alkane sulfonates might be less toxic than AS. No data are available concerning the toxicity of alkyl sulfonates on fish and algae. However, a similar toxicity might be assumed because of structural and physico-chemical similarities between the three subcategories.

For **α-olefin sulfonates**, reliable short-term tests on fish, invertebrates, and algae are available. The results indicate that toxicity is increasing as the alkyl chain length increases. The lowest available effect value is the 96 h-LC_{50} = 0.5 mg/l, determined in tests on *Oryzias latipes*, *Rasbora heteromorpha*, and *Salmo trutta*. For several substances of this subcategory the base set was incomplete (only 2 trophic levels covered). The data base for chronic toxicity is also rather small. For the whole subcategory, only one chronic *Daphnia* test, one algae NOEC and 2 subchronic fish tests are available, which were however not conducted with the most toxic substance from the acute tests. In a long-term test with sodium C_{11-14} olefin sulfonate as test substance, NOECs of 1.70 mg/l were determined for early ontogenetic stages of both the loach *Misgurnus fossilis* and the trout *Oncorhynchus mykiss*. In a test on the chronic toxicity to *Daphnia magna*, a NOEC of 6.7 mg/l for C_{14}=/$OHASO_3Na$ was obtained.

The effect of $C_{12}ASO_4Na$ on natural periphyton communities was assessed in a flow-through laboratory microcosm system. The 28 d-NOEC for algal periphyton communities was 0.055 mg/l. The ecotoxicological response of benthic and lotic microbial and invertebrate stream communities to $C_{12}ASO_4Na$ was assessed in a P&G experimental stream facility under outdoor conditions. The protozoan species richness increased with test substance concentrations, the 55 d-EC_{20} was determined to be 0.063 mg/l.

Tests on the toxicity to microorganisms were only conducted with alkyl sulfates as test substances. A test on the inhibition of respiration of activated sludge resulted in a 3 h-EC_{50} of 135 mg/l (nominally). The lowest effect value for protozoa was obtained from a test on *Uronema parduczi* using $C_{12}ASO_4Na$ as test substance, the 20 h-EC_5 was 0.75 mg/l.

Experimental test results on benthic organisms in a water-sediment system are not available. However, due to sediment-water partitioning coefficients (Kd < 350), no significant risk for organisms in this compartment is to be expected.

For terrestrial organisms no valid experimentally derived test results are available. The available toxicity data were excerpted from insufficiently documented studies. However, the data indicate that toxic effects on soil organisms might only be expected at high concentrations for alkyl sulfates. Toxicity of alkane sulfonates and α-olefin sulfonates can not be assessed because test results for terrestrial organims are not available.

5 RECOMMENDATIONS

Human Health:

This category of chemicals is currently of **low priority** for further work.

These chemicals possess properties indicating a hazard for human health (corrosion/irritation, serious effects on the eye, acute toxicity). These hazards do not warrant further work as they are related to effects which may only become evident at exposure levels that are higher than formulated in consumer products. It should nevertheless be noted by chemical safety professionals and users of the raw materials.

Environment

The following chemicals are currently of low priority for further work due to their low hazard profiles:

AS: C_8 - C_9 (acute aquatic EC/LC_{50} values >100 mg/l)

PAS: C_8 - C_{12} (acute aquatic EC/LC_{50} values >100 mg/l; chronic aquatic NOEC >1 mg/l)

The following chemicals have properties indicating a hazard for the environment:

AS: C_{10} - C_{14} & C_{18} (acute aquatic EC/LC_{50} values >1 - ≤100 mg/l; NOEC ≤ 1 mg/l)

PAS: C_{14} & C_{18} (acute aquatic EC/LC_{50} values >1 - ≤100 mg/l)

AOS: C_{12} - C_{16} (acute aquatic EC/LC_{50} values >1 - ≤100 mg/l)

However they are of low priority for further work for the environment because of their rapid biodegradation under aerobic conditions and their limited potential for bioaccumulation.

The following chemicals show acute and chronic aquatic effects at concentrations below 1 mg/l:

AS: C_{15} - C_{16} (acute aquatic EC/LC_{50} values ≤1 mg/l, NOEC ≤ 1 mg/l)

PAS: C_{15} – C_{16} (acute aquatic EC/LC_{50} values ≤1 mg/l, NOEC ≤ 1mg/l)

AOS: C_{14-18} - C_{16-18} (acute aquatic EC/LC_{50} values ≤1 mg/l)

Therefore, they should be candidates for further work. Furthermore, member countries are invited to perform an exposure assessment and if necessary a risk assessment.

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ANNEX I: CATEGORY RATIONALE FOR THE ANIONIC SURFACTANTS (ANS) CATEGORY

This category includes three structurally related classes of anionic surfactants (ANS). The category surfactants are all salts or complexes consisting of a hydrophobic, hydrocarbon chain (of varying chain length) bearing a terminal, polar, sulfur-containing anion, neutralized with a base-derived cation or an amine (e.g. sodium cation, ammonium cation, or triethanolamine).

Alkyl Sulfates (AS):	Sulfate salts consisting of a predominantly linear alkyl chain, bearing a terminal, sulfate ester anion, neutralized with a base; single chain length or a defined chain length distribution
Primary Alkane Sulfonate (PAS):	The salt of a linear saturated alkyl chain, bearing a terminal sulfonate anion, neutralized with sodium hydroxide
Alpha Olefin sulfonate (AOS):	A mixture of sodium alkene sulfonate and hydroxyl alkane sulfonate salts, with the sulfonate group in the terminal position and the double bond, or hydroxyl group, located at various positions along a linear aliphatic chain in the vicinity of the sulfonate group

The most important structural feature, the presence of an aliphatic hydrocarbon chain bearing a polar, anionic terminus, confers surfactant properties. Surfactant properties play a central role for the environmental fate and behavior as well as for the (eco)toxicity of these materials. The effects, including the impact of chain length, anionic polar terminus and positive counterion, are summarized in the tables below. Shaded fields represent endpoints with no or inadequate data for specific sub-categories.
For the PAS subgroup (6 compounds) only few experimental data are available.

PHYSICO-CHEMICAL PROPERTIES

Many of the chemicals in this category are mixtures composed of single chain length components (homologues). Property estimates are for a discrete chain length. This is because the estimation technique is based on a relationship between a specific chemical structure and a measured or estimated property of that structure. A property of a commercial mixture of linear alkyl sulfates or sulfonates is therefore a function of that property for each of the discrete chain length components in the mixture. The data availability of measured or calculated values for the three sub-categories is summarized below.

Table I-1: Data availability and results on physico-chemical properties - comparison for subcategories

Category subgroup →	Alkyl Sulfates	Primary Alkane Sulfonates	Alpha olefin Sulfonates
Melting Point	Measured data for Na salts C_8 - C_{16} calculated values for Na, K, Mg, NH_4, TEA, range C_8 - C_{18} Exp. Na values [°C]: 181 (C_8) - 193 (C_{16}); calculated values depending on counter-ion: Na, range: 232 - 286 °C; K salt values equal to Na; Mg and TEA salts higher, NH_4 lower than Na	Calculated values for Na salts Calculated values similar to alkyl sulfate values; range [°C]: 227 (C_8) - 281 (C_{18})	Calculated values for Na salts Calculated values similar to alkyl sulfate values; range [°C]: 248 (C_{12}) - 296 (C_{18})
	The chemicals of this category are predominantly applied in liquid cleaning and cosmetic products. Due to their application pattern, they enter the environment in solubilized form via the hydrosphere. Therefore, insignificant endpoint for environmental hazard assessment		
Boiling Point	Calculated values for Na, K, Mg, NH_4, TEA in the range C_8 - C_{18} available; Na, range [°C]: 542 (C_8) - 658 (C_{18}); K salt values equal to Na; Mg and TEA salts higher, NH_4 lower than Na	Calculated values for Na salts Calculated values similar to alkyl sulfate values; range [°C]: 530 (C_8) - 646 (C_{18})	Calculated values for Na salts Calculated values similar to alkyl sulfate values; range [°C]: 576 (C_{12}) - 679 (C_{18})
	Endpoint of no practical relevance; insignificant for environmental hazard assessment		
Vapor Pressure at 25 °C	Calculated values for Na, K, Mg, NH_4, TEA in the range C_8 - C_{18} available; Na, range (hPa): $1.8 \cdot 10^{-11}$ (C_8) - $3.7 \cdot 10^{-15}$ (C_{18}); K salt values similar to Na; Mg and TEA salts lower, NH_4 higher than Na	Calculated values for Na salts Calculated values similar to alkyl sulfate values; range (hPa): $4.3 \cdot 10^{-11}$ (C_8) - $9.0 \cdot 10^{-15}$ (C_{18})	Calculated values for Na salts Calculated values similar to alkyl sulfate values; range (hPa): $1.2 \cdot 10^{-12}$ (C_{12}) - $5.8 \cdot 10^{-19}$ (C_{18})
	Category compounds, due to ionic structure and formation of micelles, not volatile; hence, no partitioning to the atmosphere is to be expected		

Category subgroup →	Alkyl Sulfates	Primary Alkane Sulfonates	Alpha olefin Sulfonates
Partition Coefficient (log K_{OW})	Measured value for C_{12} Na salt; estimated values for Na, K, Mg, NH_4, TEA in the range C_8 - C_{18} available Estimated values increasing with chain length: -0.27 - 4.64 for C_8 - C_{18} Na salts; exp. value for C_{12} (1.6) corresponds to estimate (1.69) Influence of counter-ion not relevant for environment	Measured values for Na salts range: -0.7 (C_8) - 0.7 (C_{14}) Calculated values for Na salts Calculated values lower than alkyl sulfate values; range: -1.09 (C_8) - 3.82 (C_{18})	Calculated values for Na salts Calculated values lower than alkyl sulfate values; range: 0.66 (C_{12}) - 3.68 (C_{18})
	Endpoint no relevant descriptor of surfactant hydrophobicity; limited predictive value for the partitioning of these compounds in the environment		
Surfactancy CMC (mmol/l) (no specific SIDS endpoint)	Measured values for Na salts in the range C_8 - C_{18} available (distilled water) CMC decreasing with increasing chain length from C_8 (130/134 mmol/l at 20 °C) to C_{18} (0.16 mmol/l at 40 °C)	Measured values for Na salts in the range C_8 - C_{18} available (distilled water) CMC decreasing with increasing chain length from C_{10} (6.9 mmol/l) to C_{17} (0.21 mmol/l)	No experimental effect values available
	Smaller CMC values in hard water; increased surface activity due to the presence of electrolytes (Ca, Mg)		
Water Solubility	Measured data for Na salts C_{12}, C_{14}, C_{16} calculated values for Na, K, Mg, NH_4, TEA (range C_8 - C_{18}) Experim. Na salt values decreasing with increasing chain length by approx. one order of magnitude for every two carbons added to the alkyl chain: from C_{12} to C_{16}: approx. 200 000 to 300 mg/l; C_{18} is insoluble. Calculated values approx. 50 to 300-fold lower: 617 mg/l (C_{12}) - 5.0 mg/l (C_{16}); Counter-ion influences estimated water solubility	Calculated values for Na salts Calculated values about a factor of 6 higher than for the corresponding alkyl sulfates: 308 000 mg/l (C_8) - 3.09 mg/l (C_{18})	Calculated values for Na salts Calculated values by factors of approx. 10 to 100 higher than for the corresponding alkyl sulfates: approx. 5 000 mg/l (C_{12}) - 4.2 mg/l (C_{18}); presence of a hydroxyl group enhances water solubility
	Influence of counter-ion not environmentally relevant; **Values of limited practical use (micelle formation above the CMC not considered in estimation)**	**Values of limited practical use (micelle formation above the CMC not considered in estimation)**	**Values of limited practical use (micelle formation above the CMC not considered in estimation)**

The physical-chemical properties of the surfactants in this category are closely correlated with their structural properties, especially the alkyl chain length. Although being either of no (melting point, boiling point) or of only limited predictive value (log K_{OW}, water solubility, vapor pressure), the obligatory endpoints for assessing the environmental fate and behavior as well as the hazard of the ANS sub-categories are sufficiently covered by the available (measured and calculated) data.

ENVIRONMENTAL FATE AND PATHWAYS

The data availability of measured or calculated values for the three sub-categories is summarized below. Estimated properties in this section are obtained using the EPIWIN program (EPI Suite v. 3.12).

Table I-2: Data availability and results on environmental fate - comparison for subcategories

Category subgroup →	Alkyl Sulfates (AS)	Primary Alkane Sulfonates (PAS)	Alpha olefin Sulfonates (AOS)
Photodegradation	Calculated values on OH radical reaction for Na salts C_8 - C_{18}	Calculated values on OH radical reaction for Na salts	Calculated values on OH radical and ozone reaction for Na salts
	Irrelevant endpoint (however obligatory according to OECD guidance): due to lack of chromophor, no direct photolysis; indirect degradation by OH radicals in air for ANS compounds (being essentially non-volatile) not relevant		
Stability in Water	**ANS substances expected to be stable to hydrolysis under evironmentally relevant conditions**		
Volatility / Henry's law constant at 25 °C	Calculated values for Na, NH_4, TEA in the range C_8 - C_{18}; Na, range (Pa · m^3/mol): $6.0 \cdot 10^{-3}$ (C_8) - $1.0 \cdot 10^{-1}$ (C_{18}); TEA and NH_4 salts lower than Na	Calculated values for Na salts range (Pa · m^3/mol): $9.3 \cdot 10^{-3}$ (C_8) - 0.16 (C_{18});	Calculated values for Na salts range (Pa · m^3/mol): alkene sulfonates: $2.16 \cdot 10^{-2}$ (C_{12}) - 0.14 (C_{18}) Hydroxyalkane sulfonates: $1.9 \cdot 10^{-6}$ (C_{14}) - $5.8 \cdot 10^{-6}$ (C_{18})
	Due to ionic structure of ANS substances, no volatilization from water expected		
Sorption	Measured sediment-water partition coefficients for Na salts C_8-C_{14}; Calculated values for C_8-C_{18} Sorption increases with increasing chain length; for exp. values from K_{OC} 75-101 (C_8; low sorption) to approx. K_{OC} 1600 (C_{14}; strong/very strong sorption) Calculated values with same tendency significantly higher, from 883 (C_8) to approx. 35 000 (C_{14})	Calculated values for alkane sulfonate, Na salt C_8 and hydroxyl alkanes, C_{14}, C_{16}, C_{18} K_{OC}: 38 (C_8), 440 (C_{12}) to 17000 (C_{18})	Measured sediment-water partition coefficient C_{12}: 0.65 (n=1.1) Calculated values Na-salts: Alkene sulfonates: 440 (C_{12}) to 17000 (C_{18}) Hydroxylalkane sulfonates: 73 (C_{14}) to 810 (C_{18})
	Calculated values not reliable (surfactancy and dissociation not taken into account)	**Assuming same sorption mechanism and same overestimation by modeling as for AS, K_{OC} should be negligible**	**Low sorption to sediment for C_{12}; assuming same sorption mechanism and same overestimation by modeling as for AS, K_{OC} should be negligible**

Category subgroup →	Alkyl Sulfates (AS)	Primary Alkane Sulfonates (PAS)	Alpha olefin Sulfonates (AOS)
Biodegradation, aerobic	Numerous measured values for primary degradation and mineralization from guideline studies for Na, K, Mg, NH_4, MEA, TEA salts C_8-C_{18}; All tested AS fulfill the criterion of ready biodegradability based on mineralization (O_2, CO_2, DOC removal) including the 10 d window; rapid and complete elimination in simulation tests with activated sludge, in surface water and natural seawater with half-lives in the range of 0.25 - 1.0 d; biodegradation independent from the counter-ion	Measured values from OECD guideline studies on ready biodegradability for Na salts C_8-C_{18}	Measured values from OECD guideline studies on ready biodegradability for Na salts C_{12}-C_{18}; All tested Na-AOS readily biodegradable based on mineralization (O_2, CO_2, DOC removal) including the 10 d window
	All substances of the ANS category are rapidly and completely mineralized under aerobic conditions		
Biodegradation, anaerobic (no specific SIDS endpoint)	Measured values for C_{12}-C_{18} Na salts; > 80 % mineralzation after 15 d (CH_4 + CO_2)	No measured values available	Measured values from 3 non-guideline studies on C_{12} and C_{15}-C_{18} Na salts; references regarded as unreliable; Contradictory results with very slow degradation or 31/43 % degradation after 28 d (probably due to not completely anoxic conditions)
	AS mineralized under anoxic conditions	**No anaerobic biodegradation expected under anoxic conditions**	**No or at least very slow degradation under anoxic conditions expected**
Bioaccumulation (no SIDS endpoint)	Measured values for C_{12}, C_{14}, and C_{16} Na salts BCF ranging from 1.5 (C_{12}) to 73 (C_{16}); depuration: 60-120 h	No measured values available	No measured values available
	BCF and depuration indicate that AS are not expected to bioaccumulate (at least up to C_{16} chain length)	**Due to similar chemistry and physical properties, bioaccumulation potential of AOS and PAS is expected to be similar to that of the AS**	

All of the surfactants in this category are essentially non-volatile, which implies that atmospheric photodegradation is irrelevant for hazard assessment. Furthermore, they are stable to hydrolysis under environmental conditions.

Experimentally derived partition coefficients for soil/sediment-water are available for alkyl sulfates (but not for alkane sulfonates and α-olefin sulfonates) with chain lengths from C_8 to C_{14}, indicating increased adsorption when chain length increases. EPI Suite calculations on K_{OC} resulted in significantly higher values (more than 1 order of magnitude), therefore the estimates do not seem to be appropriate for the environmental exposure assessment. However, because of the common sorption mechanism (mainly hydrophobic interactions due to the alkyl chains, no ionic interactions by the functional groups) sorption of the alkene sulfonates is expected to be in the same range as for the alkane sulfates. Sorption of AOS is expected to be lower than of alkyl sulfates because of the higher polarity due to the hydroxyl group. **Consequently, the available data about adsorption are supposed to be sufficient for the environmental hazard assessment.**

Surfactants of all three sub-categories are rapidly and completely biodegraded in sewage treatment under aerobic conditions, whereas under anaerobic conditions sulfates and sulfonate-type surfactants are different in their biodegradation profile. Sulfates have been shown to mineralize under anoxic conditions, however, for the sulfonated surfactants, the weight of the evidence suggests that these do not (or only very slowly) biodegrade anaerobically, due to the recalcitrance of the C-S bond. After all, the actual effective removal of the anionic surfactants is reflected by the low concentrations measured for AS and also for AOS in different surface waters and receiving waters. **The available and reliable data are considered to adequately cover the SIDS endpoint biodegradation and support a conclusion of rapid biodegradability for the entire range of substances in the three sub-categories.**

Experimental data show, that the bioaccumulation potential of alkylsulfates in aquatic species is low (c.f. chapter 2.2.6). The chemistry and physical properties of alkane sulfonates and α-olefin sulfonates are similar to AS. **Hence, the bioconcentration tendency for AOS and alkane sulfonates are expected to be similar to those of the AS.**

ECOTOXICITY

The data availability and adequacy of experimentally derived ecotoxicity results for the three sub-categories is summarized below.

Table I-3: Data availability and results on aquatic ecotoxicity - comparison for subcategories

Category subgroup →	Alkyl Sulfates	Primary Alkane Sulfonates	Alpha olefin Sulfonates
Acute toxicity to fish	Reliable experimental effect values for Na, K, Mg, NH_4, MEA, TEA salts C_8-C_{18} from 48 studies (static, semistatic, flow-through) covering 13 freshwater and marine species; Toxicity not affected by counter-ion or test system; no species differences; toxicity predominantly determined by chain length; consistant increase of tox from C_8 to C_{13}: 48 h-LC_{50} (*Leuciscus i.*): 172 mg/l (C_8) - 2.1 mg/l (C_{13}); LC_{50} (24 - 96 h) (C_{14}/C_{15}) for different species in the range of 2.5 - 15 mg/l Inconsistency with higher chain length; further tox increase in most studies up to C_{16}, however decrease from C_{14} to C_{18} in some other studies	No experimental effect values available	Reliable experimental effect values for Na salts C_{12}-C_{18} from 15 tests (9 guideline studies; static, semistatic) covering 6 freshwater species; Toxicity predominantly determined by chain length; no species differences; continuous increase of tox from C_{12} to C_{18}: LC_{50} (48 h) C_{12}-C_{14}: > 10 mg/l LC_{50} (48 h) C_{14}-C_{18}: 1 - 10 mg/l LC_{50} (96 h) C_{14}-C_{18}: 0.5 - 5 mg/l
	Available effect values for the subgroups in the same range for comparable chain length; chain length dependency of toxicity established for AS and AOS up to chain length C_{14-15}; inconsistent results with chain length up to C_{16}/C_{18} within subgroup AS		
Long-term toxicity to fish (no SIDS endpoint)	Reliable results for Na salts C_{12}, C_{14-15} and C_{16-18} from 10 tests (2 guideline; semistatic, flow-through) covering 4 freshwater and 2 marine species; NOECs from 5 studies NOECs (C_{12} Na): > 1.36 - 4.6 mg/l comparable to acute LC_{50}s; NOEC chronic fish toxicity of C_{14-15} Na: 0.11 mg/l	No experimental effect values available	One reliable study for C_{11-14} AOS covering 2 species NOECs 1.70 mg/l

Category subgroup →	Alkyl Sulfates	Primary Alkane Sulfonates	Alpha olefin Sulfonates
Acute toxicity to invertebrates	Reliable experimental effect values for Na, K, Mg, NH_4, MEA, TEA salts C_8-C_{18} from 63 studies (mostly guideline; static, semistatic, flow-through) covering 22 freshwater, marine, and estuary species; Consistantly increasing toxicity for *Daphnia* with increasing chain length (from C_8 to C_{13}), exposure duration (24 - 48 h) EC_{50} (24/48 h) C_8-C_{10}: > 100 mg/l EC_{50} (24/48 h) C_{12}-C_{13}: 1 - 100 mg/l Inconsistency with higher chain length; further tox increase in one flow-through study up to C_{16} (for *Ceriodaphnia*), however decrease from C_{13} to C_{16} in some other studies under static exposure for *Daphnia magna*.	Reliable experimental effect values for Na salts C_8-C_{14} from 8 tests (2 guideline studies; static) covering 2 freshwater species; Increasing toxicity for *Daphnia* with increasing chain length; from C_8 (24 h EC_{50}: > 900 mg/l) to C_{14} (24 h EC_{50}: 60 - 97 mg/l)	Reliable experimental effect values for Na salts C_{14}-C_{18} from 5 guideline studies (static, semistatic) on *Daphnia magna* and *Ceriodaphnia dubia* Indication for increasing toxicity with increasing chain length from C_{14}-C_{16} (for *Daphnia*); EC_{50} (48 h) C_{14}: 14.4 mg/l EC_{50} (24 h) C_{16} and C_{14-16}: 1 - 10 mg/l EC_{50} (24 h) C_{14-18}: 7.1 - 19.2 mg/l (depending on water hardness)
	Available effect values between the subgroups in the same range for same test species and comparable chain length; chain length dependency of toxicity established for AS (chain length up to C_{13}) and indicated for PAS (chain length up to C_{14}) and AOS (chain length C_{14} to C_{16}) ; inconsistent results with chain length up to C_{16}/C_{18} within subgroup AS		
Long-term toxicity to invertebrates (no SIDS endpoint)	Reliable experimental effect values for Na salt C_{10}-C_{18} from 20 tests (static, semistatic, flow-through) covering 7 freshwater species; NOEC *Daphnia/Ceriodaphnia* (parabolic response curve) C_{12}: 0.2 - 0.9 mg/l; C_{14}, C_{14-15}: 0.05 - 0.09 mg/l C_{15}, C_{16}, C_{18}: 0.2 - 0.6 mg/l Toxicity to *Hydra* decreasing with increasing chain length from C_{10} (NOEC: 5 mg/l) to C_{16} (NOEC: ≥ 688 mg/l)	No experimental effect values available	Reliable experimental effect value for Na salt C_{14} from 1 semistatic OECD guideline test on *Daphnia magna;* 21 d-NOEC: 6.7 mg/l
Toxicity to algae / aquatic plants	Reliable experimental effect values for Na salt C_{10}-C_{18} from 14 studies (13 static, 1 flow-through) covering 3 freshwater species; 10 studies with EC_{50} values > 10 mg/l, 4 studies 1 - 10 mg/l	No experimental effect values available	Reliable experimental effect value for Na salt C_{14} and C_{14-18} from 2 static tests (1 OECD guideline test) EC_{50}: 45 and 82 mg/l; NOEC: 13 mg/l

Category subgroup →	Alkyl Sulfates	Primary Alkane Sulfonates	Alpha olefin Sulfonates
	Algae found to be less sensitive than fish and invertebrates; no indication of a chain length dependency		
Toxicity to microorganisms (no SIDS endpoint)	Reliable experimental effect values for *Pseudomonas* from 8 guideline studies for Na salts C_{12-18}, TEA C_{12-14} and MEA C_{12-14}; tests on 3 protozoa for Na salt C_{12}; *Pseudomonas* respiration inhibition: increasing toxicity with increasing chain length from C_{12} (EC_0: 9 050 mg/l) to $C_{14-18,\ 18=}$ (EC_0: 300 mg/l) Activated sludge, inhibition of respiration (C_{12}): 3 h-EC_{50} = 135 mg/l Protozoa more sensitive: lowest 20 h EC_5: 0.75 mg/l	No experimental effect values available	No experimental effect values available

The probable mode of action of the category surfactants in aquatic toxicity testing is summarized in detail in chapter 4 of the SIAR. Considering the understanding of the mechanism of toxic action of surfactants, the grouping of the anionic surfactants in this category (alkyl sulfates and alkane sulfonates with hydrophobes that differ in the length of the alkyl chain) for the purpose of risk assessment is justified.

The matrix in Table I-3 shows, that the data basis on the ecotoxicity of **alkyl sulfates** is rich and well documented. The aquatic toxicity of the category compounds is influenced by a number of parameters, the **length of the alkyl chain** being obviously most important, whereas for the counter-ion no significant influence was observed. Several studies on fish and *Daphnia* (being the most sensitive aquatic organisms), conducted under comparable experimental design, demonstrate increasing toxicity for chain lengths up to C_{14}. **This was observed in available tests for all three subcategories**. At higher chain lengths, the picture becomes inconsistent, at least for (acute) fish/*Daphnia* toxicity of the **AS** subcategory. Around C_{16} water solubility becomes the limiting factor for toxicity and, depending on the test substance, preparation of the test solutions leads to smaller or bigger micelles with differing bioavailability. Intrinsic toxicity and physical effects interfere with each other, resulting in the observed variation of ecotoxicity results. While in some test series toxicity strongly decreases up to C_{18}, other studies show increasing toxicity up to $C_{16\text{-}18}$. The **PAS** and the **AOS** subcategories include less substances. Thus, a chain length dependency of toxic effects, particularly for **PAS,** can only be indicated. For the **PAS**-subcategory acute toxicity data are available for *Daphnia magna*, but not for fish and algae. The acute toxicity of **PAS** to *Daphnia* is comparable to **AS** in the range between C_8 and C_{10}, while C_{12} and C_{14} are significantly less toxic. Taking into account the similar environmental fate and behavior as well as the similar mode of ecotoxic action, the missing effect data on fish and algae for **PAS** (at least the C_8-sulfonate) should adequately be covered by results available for the **AS** subcategory.
As far as the **AOS** subcategory is concerned, data on all acute aquatic endpoints recommended by OECD are available. Like for the **PAS**, only a limited chain length distribution was tested ($>C_{12}/C_{14}$), however, most of the available results are reliable (guideline studies) and - most important - the critical chain lengths are covered. For the most sensitive species (fish/*Daphnia*), the response pattern is only partly comparable to **AS.** While available acute fish toxicity values determined for $C_{12\text{-}14}$ **AOS** are comparable to **AS** data, **AOS** seem to be more toxic than AS at higher chain lengths (C_{16} and longer). In contrast to **AS**, there is no indication, that the toxicity of **AOS** may decrease at higher chain lengths. Whereas the effects of AOS on daphnids are comparable to **AS** data for the C_{14} chain length, results for chain lengths > 14 cannot be compared with **AS** values, due to the observed scattering of results with higher homologues of **AS**.

Summary

The anionic surfactants (ANS) share similarities in structure, function (surfactancy) as well as in their environmental degradation, sorption and accumulation potential. These factors support treating the HPV surfactants, and related chemicals that provide supporting data, as a single, chemical category.

For the ecotoxic effects on aquatic organisms, the **length of the alkyl chain** is the most important determining parameter. Several studies, conducted under comparable experimental design, demonstrate consistently an increasing toxicity for category surfactants with chain lengths up to C_{14}, allowing a read-across for uncovered endpoints. Higher homologues exhibit a scattering response pattern in and between the three subcategories, however, due to the reasons laid down above, the data available on ecotoxic effects are supposed to be sufficient for an environmental hazard assessment for all three subcategories.

TOXICITY

For the alkyl sulfates, numerous studies with detailed information are available for each SIDS endpoint (see Table I-4). The database includes compounds of different chain lengths ($C_{8\text{-}18}$, even and odd numbered) as well as different counter ions:

Table I-4: Overview on the availability of toxicological studies and comparison of the observed effects

	Data availability (Chain lengths, counter ions) Results for sub-category		
	ASO4	**ASO3**	**A=/OHSO3**
Metabolism and Excretion	C_{10}, C_{11}, C_{12}, C_{16}, C_{18} Na, K, TEA	C_{12}, C_{16} Na	C_{14}
Excretion in urine	C_{12} (complete within 6 h) $C_{10, 11,16, 18}$ (mainly within 48 h)	C_{12}, C_{16} (not complete within 6 h)	C_{14} (not complete within 24 h)
Amounts excreted in urine (% of dose in 48 h)	C_{10-18} 74 – 98 % (5 mg/kg , oral)	C_{12}: 87 – 96 % (5 mg/kg oral) C_{16}: 48 – 65 % (5 mg/kg oral)	C_{14}: 72 % (100 mg/kg oral, 5 days)
Amounts excreted in feces (% of dose in 48 h)	C_{12}: negligible $C_{11, 18}$: < 10 % as metabolites	C_{12}: < 10 % unabsorbed C_{16}: 40 % unabsorbed	C_{14}: 22 % (mainly unabsorbed, 5 days)
Main metabolites	Even chain numbers: Butyric acid 4-sulfate Odd chain number: Propionic acid-3-sulfate, pentanoic acid-5-sulfate Sulfate	Even chain number: Buyric acid 4-sulfonate Odd chain number: not investigated No Sulfate	No data
Distribution	C_{10}, C_{12}, C_{18} K Whole body autoradiography after i.p. application Liver, kidney	C_{12}, C_{16} Na Whole body autoradiography after i.p. application Liver, kidney	C_{14} Na Radioactivity in organs after oral application Gastrointestinal tract, liver, kidney
Acute oral toxicity LD_{50}	C_{8-18} (various mixtures) Na, NH4, MEA, TEA C10: 290-580 mg/kg C10-16, C12: 1000 – 2000 mg/kg C12-14, C12-15, C12-16, C12-18, C18: > 2000 mg/kg C16.18: > 5000 mg/kg	C_8 Na > 5000 mg/kg	C_{14-18} (mixtures) Na 578 – 2430 mg/kg

	Data availability (Chain lengths, counter ions) Results for sub-category		
	ASO4	**ASO3**	**A=/OHSO3**
Skin irritation	C_{8-18} (various mixtures) Na, K, Mg, NH4, MEA, TEA irritating to corrosive $C_{12}ASO_4$ highest activity activity decreases with increasing chain length	no data	C_{14-18} Na slightly irritating to irritating
Eye irritation	C_{8-18} (various mixtures) Na, Mg, MEA, NH4, TEA irreversible effects for $C_{12}ASO_4$ Na to mildly irritating for $C_{16-18}ASO_4$ Na activity decreases with increasing chain length	no data	C_{14-16} Na irreversible effects to the eyes (as 90 % active substance) or not irritating (as 40 % active substance)
Sensitization	C_{8-18} (various mixtures) Na, Mg, NH4, MEA, TEA not sensitizing	no data	C_{14-16} Na not sensitizing
Repeated dose toxicity oral application	C_{12-18} (various mixtures) Na, TEA Studies with rats: Lowest NOAEL, 13w: 86 mg/kg bw/day (C12) Lowest LOAEL, 13w: 230 mg/kg bw/day (C16-18; liver toxicity)	no data	C_{14-16} Na Studies with rats: NOAEL: ca. 100 mg/kg bw/day LOAEL: 200-250 mg/kg mg/kg bw (weight gain ↓)
Mutagenicity			
in vitro Bacteria	C_{8-18} (various mixtures) Na, Mg, MEA, TEA, NH4 Ames Test Not mutagenic	no data	C_{14-16} Na Ames Test Not mutagenic
in vitro mammalian cells	C_{12}, C_{14}, C_{16} Na Mouse lymphoma assay SCE assay negative	no data	C_{14-16} Na Chromosome aberration test (V79 / CHL) negative
in vivo	C_{12-18} (various mixtures) Na, TEA Micronucleus assay Chromosome aberration assay negative one positive result in chromosome aberration assay	no data	no data

	Data availability (Chain lengths, counter ions) Results for sub-category		
	ASO4	**ASO3**	**A=/OHSO3**
	with C_{12-15} ASO_4 Na		
Carcinogenicity			
Dermal	no data	no data	C_{14-16} Na Studies with mice and rats negative
Oral	C_{12-15} (several studies) Na Studies with rats negative	no data	C_{14-16} Na Studies with rats negative
Reproduction toxicity			
Fertility	C_{12} Na impairment of epididymal spermatozoa negative No histopathological changes in repeated dose toxicity studies	no data	C_{14-16} Na 2-generation reproductive toxicity negative No histopathological changes in repeated dose toxicity studies
Developmental toxicity	C_{12-18} (several studies) Na adverse effects in offspring only at maternally toxic doses C_{12} Na sensitivity rabbits > mice > rats	no data	C_{14-16} Na adverse effects in offspring only at maternal toxic doses Sensitivity rabbits > mice > rats rats: no effects in dams and offspring at up to 600 mg/kg bw (highest dose tested)

All alkyl sulfates show a very similar oral absorption, excretion profile and metabolites. Butyric acid-4-sulfate and sulfate are the main metabolites irrespective of chain length for the even numbered alkyl sulfates and propionic acid-3 sulfate, pentanoic acid-5-sulfate and sulfate are the main metabolites for the odd numbered alkyl sulfates. Compared to compounds with other chain lengths, for $C_{12}ASO_4$ a higher oral absorption and faster metabolism/excretion was observed. The acute oral toxicity for all compounds is low and only unspecific signs of intoxication were observed. In longer-term studies all compounds showed a strikingly similar pattern of effects (target organs are liver and kidneys) and the NOAEL and LOAEL ranges were similar. There was no difference between mixtures with even or odd chain lengths. In Ames tests with various different mixtures as well as with eukaryotic test systems consistently negative results were obtained. The database on genotoxicity is considered as sufficient, as several in vivo studies with compounds of different chain lengths are available, i.e. micronucleus test and chromosome aberration test. Apart from one exception - a chromosome aberration assay with hamsters - all other studies gave negative results. There are also oral carcinogenicity studies on several mixtures available, which all were negative.

Effects of counter ions

In aqueous environments the salts will dissociate, so that the counter ions will not fundamentally alter pathways of tissue disposition, metabolism, excretion, or target organs of toxicity. Accordingly no major differences were found in most of the endpoints between the compounds with different counter ions. Furthermore this is consistent with the low toxicity of the counter ions (see reviews for monoethanolamine [BUA, 1996[5]], triethanolamine [BG Chemie, 1990[6]] or ammonia [ATSDR, 2004[7]]). However, the irritancy is influenced by the counter ion, as TEA seems to reduce the skin irritating properties of the compounds compared with sodium, magnesium or ammonium.

Alkyl sulfonates

As shown in Table I-4, for nearly all endpoints data are missing. However, the sulfonates in general have been subject of a category approach of the German BUA (Greim et al., 1994[8]). It shows similarities for all members of the group irrespective of their structure. They are quickly eliminated, the acute and repeated dose toxicity is low, there was no incication for genotoxic effects and the results of teratogenicity studies were negative. This is in compliance with data obtained for the alkyl sulfates and olefin sulfonates.

Olefin sulfonates

For the olefin sulfonates several studies are available and all SIDS endpoints are covered (see Table I-4). The chain lengths investigated cover $C_{14\text{-}18}$ with sodium as counter ion. The observed effects are very similar compared with the alkyl sulfates, and no difference was seen between the different mixtures. The compounds are eliminated mainly in the urine, the acute oral toxicity is low and all mixtures showed irritating properties without a sensitizing potential. Target organs in repeated oral dose studies also were liver and kidneys. The olefin sulfonates were not mutagenic in vitro and no increased tumor rates were found in dermal and oral carcinogenicity studies.

[5] BUA (1996) Monoethanolamin. BUA-Report No. 202 (summary is attached)
[6] BG Chemie (1990) Toxicological Evaluation of 102-71-6 Triethanolamin (BG No. 57)
[7] ATSDR (2004) Toxicological Profile for Ammonia
[8] Greim H et al. (1994) Toxicity and ecotoxicity of sulfonic acids: structure-activity relationship. Chemosphere 28, 2203 - 2236

Comparison of the three subgroups

The toxicological profile of the alkyl sulfates and the olefin sulfonates reveals many similarities (see Table I-4). For all compounds the acute oral toxicity as well as repeated oral toxicity is low. After multiple oral dosing, the gastrointestinal tract (dosing via gavage), liver and kidneys were identified as target organs. The similarity between both subgroups is evident also for all other endpoints such as skin and eye irritation, sensitization, mutagenicity, carcinogenicity and reproductive toxicity.
The database for the alkyl sulfonates is very limited. These substances are in between the two other groups, as they share the saturated alkyl chain with the alkyl sulfates and the sulfonic acid group with the olefin sulfonates. As for the alkyl sulfates and olefin sulfonates, the acute oral toxicity is low. If additional data for the sulfonates (see above) are taken into account, it can be assumed that the alkyl sulfonates also will cause skin and eye irritation, but no sensitizing or genotoxic (in vitro) effects. Longer-term studies as well as data concerning carcinogenicity or reproduction toxicity are missing. However, based on metabolism studies it can be concluded that the toxicokinetic properties of the alkyl sulfates and sulfonates are similar. In addition, the sulfonic acids are also distributed within the body only to the liver and kidneys. Therefore also an analogy of the target organs can be assumed (i.e. a possible difference in metabolites may not play a role in the toxicity of these compounds) and adverse effects for the so far missing endpoints are not to be expected.

In summary, the available toxicological data are supporting the common properties of the compounds of the whole category.

ANNEX II

Table II-1: Estimated [1)] and measured physico-chemical properties of alkyl sulfates

Melting point (°C)						
Shorthand	Na	K	NH_4	TEA	Mg	Na (exp.)
C_8 ASO_4	232			288		181–183
C_{10} ASO_4	243		207	299	284	ca. 197
C_{12} ASO_4	254	254	218	310	305	193 / 204-207
C_{13} ASO_4	259	259				ca. 194
C_{14} ASO_4	265	265	229	321	327	ca. 196
C_{15} ASO_4	270					ca. 186
C_{16} ASO_4	276	276	240	332	349	ca. 193
C_{18} ASO_4	286	286		343		
C30 ASO4				350		
Boiling point (°C)						
Shorthand	Na	K	NH_4	TEA	Mg	Na (exp.)
C_8 ASO_4	542			662		
C_{10} ASO_4	565		489	685	652	
C_{12} ASO_4	589	589	512	709	699	
C_{13} ASO_4	600	600				
C_{14} ASO_4	612	612	535	732	745	
C_{15} ASO_4	623					
C_{16} ASO_4	635	635	558	755	792	
C_{18} ASO_4	658	658		778		
C_{30} ASO4				918		
Vapor pressure at 25 °C (hPa)						
Shorthand	Na	K	NH_4	TEA	Mg	Na (exp.)
C_8 ASO_4	$1.8 \cdot 10^{-11}$			$1.0 \cdot 10^{-19}$		
C_{10} ASO_4	$3.4 \cdot 10^{-12}$		$8.3 \cdot 10^{-10}$	$1.2 \cdot 10^{-20}$	$5.6 \cdot 10^{-15}$	
C_{12} ASO_4	$2.4 \cdot 10^{-12}$	$6.3 \cdot 10^{-13}$	$1.6 \cdot 10^{-10}$	$1.3 \cdot 10^{-21}$	$1.7 \cdot 10^{-16}$	
C_{13} ASO_4	$2.7 \cdot 10^{-13}$	$2.7 \cdot 10^{-13}$				
C_{14} ASO_4	$1.1 \cdot 10^{-13}$	$1.1 \cdot 10^{-14}$	$3.0 \cdot 10^{-11}$	$1.5 \cdot 10^{-22}$	$5.2 \cdot 10^{-18}$	
C_{15} ASO_4	$4.9 \cdot 10^{-14}$					
C_{16} ASO_4	$2.1 \cdot 10^{-14}$	$2.1 \cdot 10^{-14}$	$5.7 \cdot 10^{-12}$	$1.6 \cdot 10^{-23}$	$1.5 \cdot 10^{-19}$	
C_{18} ASO_4	$3.7 \cdot 10^{-15}$	$3.7 \cdot 10^{-15}$		$1.8 \cdot 10^{-24}$		
C_{30} ASO4				$1.4 \cdot 10^{-29}$		
Water solubility at 25 °C (mg/l)						
Shorthand	Na	K	NH_4	TEA	Mg	Na exp.
C_8 ASO_4	50570			1719		
C_{10} ASO_4	5133		182	168	$5.1 \cdot 10^{-6}$	
C_{12} ASO_4	617	415	18	16	$4.6 \cdot 10^{-8}$	196 000 (20 °C)
C_{13} ASO_4	163	131				
C_{14} ASO_4	51	41	1.8	1.6	$4.2 \cdot 10^{-10}$	2 370
C_{15} ASO_4	16					
C_{16} ASO_4	5.0	4.0	0.18	0.15	$3.7 \cdot 10^{-12}$	300 (30 °C)
C_{18} ASO_4	0.49	0.39		0.015		insoluble
C_{30} ASO4				$1.1 \cdot 10^{-8}$		
n-Octanol/water-partition coefficient						
Shorthand	Na	K	NH_4	TEA	Mg	Na exp.
C_8 ASO_4	-0.27			0.58		
C_{10} ASO_4	0.71		2.44	1.57	9.55	
C_{12} ASO_4	1.69	1.69	3.42	2.55	11.51	1.6
C_{13} ASO_4	2.18	2.18				
C_{14} ASO_4	2.67	2.67	4.40	3.53	13.48	

C_{15} ASO_4	3.17					
C_{16} ASO_4	3.66	3.66	5.39	4.51	15.44	
C_{18} ASO_4	4.64	4.64		5.50		
C_{30} ASO4				11.39		
Henry's law constant at 25 °C (Pa · m^3/mol) (bond method)						
Shorthand	Na	K	NH_4	TEA	Mg	Na exp.
C_8 ASO_4	$6.0 \cdot 10^{-3}$			$2.0 \cdot 10^{-17}$		
C_{10} ASO_4	$1.1 \cdot 10^{-2}$		$5.1 \cdot 10^{-11}$	$3.4 \cdot 10^{-17}$	incomplete	
C_{12} ASO_4	$1.9 \cdot 10^{-2}$	incomplete	$8.9 \cdot 10^{-11}$	$6.1 \cdot 10^{-17}$	incomplete	
C_{13} ASO_4	$2.5 \cdot 10^{-2}$	incomplete				
C_{14} ASO_4	$3.3 \cdot 10^{-2}$	incomplete	$1.6 \cdot 10^{-10}$	$1.1 \cdot 10^{-16}$	incomplete	
C_{15} ASO_4	$4.4 \cdot 10^{-2}$					
C_{16} ASO_4	$5.8 \cdot 10^{-2}$	incomplete	$2.8 \cdot 10^{-10}$	$1.9 \cdot 10^{-16}$	incomplete	
C_{18} ASO_4	$1.0 \cdot 10^{-1}$	incomplete		$3.3 \cdot 10^{-16}$		
C_{30} ASO4				$1.0 \cdot 10^{-14}$		

[1]) EPI Suite v3.12

Table II-2: Estimated [1)] physico-chemical properties of alkane sulfonates

Chemical Shorthand	**Melting Point (°C)**	**Boiling Point (°C)**	**Vapor Pressure at 25 °C (hPa)**	**Octanol/Water Partition Coefficient**		**Water Solubility at 25 °C (mg/l)**	**Henry's law constant at 25 °C (Pa · m^3/mol) (bond method)**
				calculated	**measured**		
C_8 ASO_3 Na	227	530	$4.3 \cdot 10^{-11}$	-1.09	-0.7	308 000	$9.3 \cdot 10^{-3}$
C_{10} ASO_3 Na					-.0.3		
C_{12} ASO_3 Na	248	576	$1.5 \cdot 10^{-12}$	0.87	0.2	2.682	$2.9 \cdot 10^{-2}$
C_{14} ASO_3 Na					0.7		
C_{18} ASO_3 Na	281	646	$9.0 \cdot 10^{-15}$	3.82	-	3.092	0.16

[1]) EPI Suite v3.12

Table II-3: Estimated [1)] physico-chemical properties of alpha-olefin sulfonates: alkene sulfonates [2)]

Chemical Shorthand	**Melting Point (°C)**	**Boiling Point (°C)**	**Vapor Pressure at 25 °C (hPa)**	**Octanol/Water Partition Coefficient (log K_{OW})**	**Water Solubility (mg/l)**	**Henry's law constant at 25 °C (Pa · m^3/mol) (bond method)**
C_{12} =ASO_3 Na	250	580	$1.2 \cdot 10^{-12}$	0.66	4982	$2.54 \cdot 10^{-2}$
C_{14} =ASO_3 Na	261	603	$2.1 \cdot 10^{-13}$	1.64	498	$4.5 \cdot 10^{-2}$
C_{16} =ASO_3 Na	272	626	$3.9 \cdot 10^{-14}$	2.62	49	$7.9 \cdot 10^{-2}$
C_{18} =ASO_3 Na	283	650	$6.9 \cdot 10^{-15}$	3.60	4.9	0.14

[1]) EPI Suite v3.12 [2)] alpha-olefin sulfonates are mixtures of two components: mono-unsaturated alkene sulfonates and hydroxyalkane sulfonates.

Table II-4 Estimated [1)] physico-chemical properties of alpha-olefin sulfonates: hydroxyalkane sulfonates [2)]

Chemical Shorthand	Melting Point (°C)	Boiling Point (°C)	Vapor Pressure at 25 °C (hPa)	Octanol/Water Partition Coefficient (log K_{OW})	Water Solubility at 25 °C (mg/l)	Henry's law constant at 25 °C ($Pa \cdot m^3/mol$) (bond method)
C_{14} $OHASO_3$ Na	274	632	$3.3 \cdot 10^{-17}$	0.32	5268	$1.9 \cdot 10^{-6}$
C_{16} $OHASO_3$ Na	285	656	$4.4 \cdot 10^{-18}$	1.30	519	$3.3 \cdot 10^{-6}$
C_{18} $OHASO_3$ Na	296	679	$5.8 \cdot 10^{-19}$	2.28	51	$5.8 \cdot 10^{-6}$

[1)]) EPI Suite v3.12 [2)] alpha-olefin sulfonates are mixtures of two components: mono-unsaturated alkene sulfonates and hydroxyalkane sulfonates.

ANNEX III

Table III-1: Biodegradation of Alkyl Sulfates

Test Substance (CAS No.)	Chain length	Counter ion	Guideline	Inoculum	Result	Reliability score[1)]	Reference
142-31-4	**8**	**Na**	**OECD 301 D**	**STP effluent**	**91 % BOD/COD in 30 d 10 d time window fulfilled readily biodegradable**	**2**	**Cognis (2001h) R-0100620**
			OECD 301 E		**ca. 100 % in 8 d**	**2**	**Sanchez Leal et al. (1991)**
1072-15-7	9	Na	No data available				
142-87-0	**10**	**Na**	**OECD 301 D**	**STP effluent**	**99 % BOD/COD in 15 d 14 d time window fulfilled readily biodegradable**	**2**	**Cognis (2001i) R-0100621**
			OECD 301 E		**ca. 90 % in 8 d**	**2**	**Sanchez Leal et al. (1991)**
7739-63-1	10	K	No data available				
39943-70-9	10	TEA	No data available				
99999-99-9	11	K	No data available				
151-21-3	**12**	**Na**	**OECD 301 D**	**STP effluent**	**94 / 97 % BOD/COD in 28 d 10 d time window fulfilled readily biodegradable**	**1**	**Henkel KGaA (1996b) R 9601579**
			EEC Annex V Part C 5.2	**Soil Loam 1 Loam 2 STP effluent**	**90 - 94 % BOD/COD in 30 d 99 % MBAS in 30 d readily biodegradable**	**2**	**Richterich and Gerike (1986)**
			P&G method River water die away test	**River water + sediment**	**Half-life: 0.6 - 1.0 d (CO_2)**	**2**	**Procter and Gamble (1993a) # 93-017**
			Activated sludge units, Bundesgesundheitsblatt part I (1962)	**Activated sludge**	**94 - 99 % TOC 99.5 - 99.7 % MBAS**	**2**	**Janicke (1971)**
			Closed Bottle Test		**Ca. 85 % BOD/COD in 30 d 99 % MBAS in 30 d readily biodegradable**	**2**	**Fischer and Gerike (1975)**
			Confirmatory Test (1970)		**99 % COD**	**2**	**Fischer and Gerike (1975)**
			Coupled Units Test (1970)		**96 / 106 % COD**	**2**	**Fischer and Gerike (1975)**
			Coupled Units Test (1973)	**Activated sludge, domestic**	**107 % DOC**	**2**	**Gerike and Fischer (1979)**
			Zahn-Wellens Test (1976)	**Activated sludge, industrial**	**97 % DOC in 14 d inherently biodegradable**	**2**	**Gerike and Fischer (1979)**

			OECD 301 C		**100 - 104 % BOD/TOD in 14 d 10 d time window fulfilled readily biodegradable**	**2**	**Urano and Saito (1985)**
			Modified MITI Test		**93 % DOC in 14 d readily biodegradable**	**2**	**Gerike and Fischer (1979)**
			AFNOR (1977)		**100 % DOC in 42 d**	**2**	**Gerike and Fischer (1979)**
			Sturm-Test (1973)		**82 % CO_2 in 28 d 69 % DOC in 28 d readily biodegradable**	**2**	**Gerike and Fischer (1979)**
			Modified OECD Screening Test	**STP effluent**	**107 % DOC in 19 d readily biodegradable**	**2**	**Gerike and Fischer (1979)**
			Closed Bottle Test (1974)		**85 % DOC in 30 d readily biodegradable**	**2**	**Gerike and Fischer (1979)**
			OECD 301 E		**ca. 100 % in 8 d**	**2**	**Sanchez Leal et al. (1991)**
			Pitter	**Activated sludge, adapted**	**97 % COD in 3 d 100 % MBAS in 3 d inherently biodegradable**	**2**	**Pitter and Fuka (1979)**
				Seawater	**Half-life: 0.26 - 0.34 d (MBAS)**	**2**	**Vives-Rego et al. (1987)**
			Shake-flask Exp.	**Activated sludge**	**Micelle formation inhibited biodegradation**	**2**	**Zhang et al. (1999)**
			Shake-flask Exp.	**Diesel-oil degrading bacteria**	**16 of 29 strains degraded test substance; Optimal degrading temp. 20 - 25 °C**	**2**	**Margesin and Schinner (1998)**
				Pseudomonas C12B	**Presence of sediment accelerates biodegradation**	**2**	**Marchesi et al. (1997)**
				Pseudomonas C12B	**Presence of sediment accelerates biodegradation**	**2**	**Marshall, House, and White (2000)**
4706-78-9	12	K	No data available				
2235-54-3	**12**	**NH_4**	**No data available**				
139-96-8	**12**	**TEA**	**No data available**				
3026-63-9	13	Na	No data available				
1191-50-0	14	Na	OECD 301 B	Activated sludge, non-adapted	78.4 / 80 % $ThCO_2$ in 36 d 50 % $ThCO_2$ in 5 d	4	Procter and Gamble (1995a)
			OECD 301 E		ca. 100 % in 8 d	2	Sanchez Leal et al. (1991)
			River water die-away test	Sewage effluent (domestic)	Total degradation (CO_2 + biomass): 67.9 % in 1 h 87 % in 30 h 96.4 % in 144 h Half-life 0.22 h (primary degradation)	4	Procter and Gamble (1996d) # 94-009

			Aerobic die-away test in activated sludge	Activated sludge	Total degradation (CO_2 + biomass): 54 % in 15 min 63 % in 1 h 77 % in 24 h	4	Procter and Gamble (1996b) # E95-023
			Anaerobic die-away test	Digester sludge	80 % CO_2 + CH_4 in 15 d	2	Nuck and Federle (1996)
13393-71-0	15	Na	No data available				
1120-01-0	16	Na	OECD 301 D	STP effluent	69 % ThOD in 30 d 10 d window fulfilled readily biodegradable	2	Cognis (2001j) R-0100622
7065-13-6	16	K	No data available				
1120-04-3	18	Na	OECD 301 D	STP effluent	70 % ThOD in 30 d 10 d window fulfilled readily biodegradable	2	Cognis (2001k) R-0100624
90583-19-0	8-14	Li	No data available				
90583-10-1	8-14	NH_4	OECD modified screening test	STP effluent (domestic)	96 % DOC in 28 d 96 % TOC in 28 d readily biodegradable	2	Henkel KGaA (1991a) # 8248/202-1
85665-45-8	8-14	TEA	OECD 301 D	STP effluent (domestic)	92 - 97 % BOD/COD in 30 d passlevel not reached, readily biodegradable	2	Cognis (2003a) R 0300615
90583-27-0	8-16	Na	OECD 301 D	STP effluent (domestic)	> 87 - 96 % BOD/COD in 30 d 10 d time window fulfilled readily biodegradable	2	Cognis (2003c) R 0300616
68585-47-7	**10-16**	**Na**	**No data available**				
68081-97-0	10-16	Mg	No data available				
68081-96-9	**10-16**	**NH_4**	**No data available**				
117875-77-1	**10-16**	**TEA**	**No data available**				
68611-55-2	10-16		No data available				
91783-23-2	12-13	Na	EEC method; act. sludge simul. test	Activated sludge	94.5 % DOC in 0.25 d 99.7 % MBAS in 0.25 d	1	Shell (1992b) SBGR.92.285
			OECD 301 F	Activated sludge	74 - 83 % (O_2-uptake) in 28 d 87 - 93 % (DOC) in 28 d 100 % (MBAS) 10 d window fulfilled readily biodegradable	2	Shell (1992a) SBGR.92.116
			OECD 302 A	Mixed liquor + settled STP influent (1:3)	95 ± 3 % DOC in 23 d	1	Procter and Gamble (1991c) WB-05-011
			84/449/EEC	Activated sludge	79 - 82 % $ThCO_2$ 88 - 91 % DOC 99 % MBAS	2	Shell (1992a) SBGR.92.116
				Anaerobic sludge	37 - 80 %	2	Shell (1992a) SBGR.92.116
91783-22-1	12-13	K	No data available				

85586-07-8	**12-14**	**Na**	**P. Gerike metabolite test**	**Activated sludge**	**100 % biodegradation in 30 d, no recalcitrant metabolites**	**2**	**Procter and Gamble (1992a) E 2089-11**
			OECD 301 D	**Domestic sewage**	**96 - 102 % BOD/COD in 28 d 10 d time window fulfilled readily biodegradable**	**2**	**Henkel KGaA (1996a) R 9600071**
				Anaerobic sludge	**77 - 157 % CH_4 in 40 - 50 d 99 % MBAS**	**2**	**Salanitro and Diaz (1995)**
90583-23-6	12-14	Mg	OECD 301 E	STP effluent (domestic)	93 - 99 % DOC in 28 d 10 d window fulfilled readily biodegradable	**2**	Henkel KGaA (1992a) #8249/202-1
90583-16-7	12-14	MEA	OECD 301 D	Domestic sewage	71 / 90 % BOD/COD in 28 d 10 d window fulfilled readily biodegradable	**2**	**Henkel KGaA (1992f) RE 910094**
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**OECD 301 E**	**STP effluent (domestic)**	**97 - 98 % DOC in 28 d 10 d window fulfilled readily biodegradable**	**2**	**Henkel KGaA (1999a) R 9900949**
68890-70-0	**12-15**	**Na**	**OECD 301 F**	**Activated sludge**	**80 - 81 % (O_2 uptake) 57 - 60 % (DOC) 99 % (MBAS) 10 d window fulfilled readily biodegradable**	**2**	**Shell (1992a) SBGR.92.116**
			84/449/EEC	**Activated sludge**	**75 - 97 % $ThCO_2$ 88 - 95 % DOC 99 % MBAS**	**2**	**Shell (1992a) SBGR.92.116**
				Anaerobic sludge	**41 - 59 %**	**2**	**Shell (1992a) SBGR.92.116**
73296-89-6	**12-16**	**Na**	**ECETOC Anaerobic biodegradation**	**Anaerobic sludge**	**89.8 % after 35 d**	**1**	**Cognis (2003b) R-0300617**
			static die away test	**according to the EMPA method**	**100 % after 4 d**	**2**	**Gafa and Lattanzi (1975)**
90583-12-3	**12-16**	**NH_4**	**No data available**				
68955-19-1	**12-18**	**Na**	**OECD 301 D**	**Activated sludge**	**74 - 100 % $ThCO_2$ in 30 d 14 d window fulfilled readily biodegradable**	**2**	**Cognis (2004a) R 0400408**

Test Substance (CAS No.)	Chain length	Counter ion	Guideline	Inoculum	Result	Reliability score[1)]	Reference
68955-19-1	**12-18**	**Na**	**OECD 302 A**	**Mixed liquor + settled STP influent (1:3)**	**97 ± 3 % DOC**	**1**	**Procter and Gamble (1991b) WB-05-010**
			84/449/EEC, C.6 OECD 301 D	**STP effluent**	**> 100 % in 30 d**	**2**	**Henkel KGaA (1995c) No. 6269**
90583-24-7	**12-18**	**K**	**No data available**				
90583-13-4	12-18	NH_4	OECD 301 E	STP effluent (domestic)	91 - 94 % DOC in 28 d 90 - 93 % TOC in 28 d 10 d window fulfilled readily biodegradable	2	Henkel KGaA (1992b) #8253/202-1
99999-99-9	12-18	Mg	No data available				
86014-79-1	13-15	Na	No data available				
91648-54-3	14-15	Na	OECD 301 F	Activated sludge	77 - 96 % (O_2-uptake) in 28 d 71 % (DOC) in 28 d 100 % (MBAS) in 28 d 10 d window fulfilled readily biodegradable	2	Shell (1992a) SBGR.92.116
			EEC method; act. sludge simul. test	Activated sludge	92.7 % (DOC) in 57 d 100 % MBASin 57 d	1	Shell (1992b) SBGR.92.285
			84/449/EEC	Activated sludge	58 - 76 % $ThCO_2$ in 28 d 83 - 90 % DOC in 28 d 99 % MBAS in 28 d	2	Shell (1992a) SBGR.92.116
				Anaerobic sludge	40 - 82 %	2	Shell (1992a) SBGR.92.116
				Anaerobic sludge	65 - 120 % CH_4 in 40 - 50 d 96 - 99 % MBAS	2	Salanitro and Diaz (1995)
68081-98-1	**14-18**	**Na**	**No data available**				
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available				
90583-31-6	14-18 & 18 unsatd.	Na	OECD 301 D	STP effluent (domestic)	72 - 73 % BOD/COD in 28 d 10 day time window fulfilled readily biodegradable	2	Henkel KGaA (1991l) # 8186/201-1
			ECETOC Anaerobic biodegradation	Anaerobic sludge	96.9 % after 71 d	1	Henkel KGaA (1992l) #8299/224-1
99999-99-9	15-16		No data available				
68955-20-4	**16-18**	**Na**	**OECD 301 D**	**STP effluent**	**77 % BOD/COD in 30 d 14 d window fulfilled readily biodegradable**	**2**	**Cognis (2001v) R-0100631**
			OECD 303 A	**Activated sludge, adapted**	**96 ± 2 % removal of DOC 92 ± 4 % removal of TOC**	**2**	**Cognis (2001l) R-0100632**

[1)] Reliability score specified in the IUCLID data sheet for each compound

Table III-2: Biodegradation of Alkane sulfonates and α-Olefin sulfonates

Test Substance (CAS No.)	Chain length	Counter ion	Guideline	Inoculum	Result	Reliability score[1)]	Reference
ALKANE SULFONATES							
5324-84-5	**8**	**Na**	**OECD 301 B**	**activated sludge**	**53 / 56 % $ThCO_2$ in 35 d 88 / 87 % DOC in 35 d readily biodegradable based on DOC**	**1**	**Stepan Co. (1994)**
			OECD 301 E		**ca. 95 % in 14 d**	**2**	**Sanchez Leal et al. (1991)**
13419-61-9	10	Na	OECD 301 E		ca. 90 % in 16 d	2	Sanchez Leal et al. (1991)
2386-53-0	12	Na	OECD 301 E		ca. 95 % in 16 d	2	Sanchez Leal et al. (1991)
27175-91-3	14	Na	OECD 301 E		ca. 95 % in 14 d	2	Sanchez Leal et al. (1991)
13893-34-0	18	Na	OECD 301 D	garden mould suspension	81 % BOD/COD in 30 d 10 d window not fulfilled readily biodegradable	2	Cognis (2001p) R-0100941
	12-18	Na	Pitter	Activated sludge, adapted	90 % COD in 8 d 98.2 % MBAS in 8 d inherently biodegradable	2	Pitter and Fuka (1979)
68815-15-6	15-18	Na	No data available				
α-OLEFIN SULFONATES							
30965-85-6	12	Na	OECD 301 D	garden mould suspension	100 % BOD/COD in 30 d 10 d window fulfilled readily biodegradable	2	Cognis (2001n) R-0100907
			OECD 301 C		62 - 100 % BOD/TOD in 14 d readily biodegradable	2	Urano and Saito (1985)
			Modified shake-flask	Secondary municipal waste water effluent, adapted	ca. 60 % CO_2 in 10 d ca. 95 % MBAS in 4 d readily biodegradable	2	Kravetz, Chung, and Rapean (1982)
				Anaerobic	From a number of surfactants testet AOS was least degraded	4	Itoh, Naito, and Unemoto (1987)
93686-14-7	**14**	**Na**	**OECD 301 C**	**Activated sludge, non-adapted**	**BOD = 61, 66, 74 % in 28 d TOC = 79, 86, 89 % readily biodegradable**	**1**	**MITI (1995)**
			Modified shake-flask	**Secondary municipal waste water effluent, adapted**	**ca. 60 % CO_2 in 10 d ca. 98 % MBAS in 4 d readily biodegradable**	**2**	**Kravetz, Chung, and Rapean (1982)**

Test Substance (CAS No.)	Chain length	Counter ion	Guideline	Inoculum	Result	Reliability score[1)]	Reference
11067-19-9	16	Na	OECD 301 D	garden mould suspension	82 % ThOD in 30 d 10 d window fulfilled readily biodegradable	2	Cognis (2001o) R-0100938
			Modified shake-flask	Secondary municipal waste water effluent, adapted	ca. 55 % CO_2 in 10 d ca. 97 % MBAS in 4 d readily biodegradable	2	Kravetz, Chung, and Rapean (1982)
	18	Na	Modified shake-flask	Secondary municipal waste water effluent, adapted	ca. 55 % CO_2 in 16 d ca. 97 % MBAS in 4 d readily biodegradable	2	Kravetz, Chung, and Rapean (1982)
85536-12-5	12-14	Na	OECD 301 D	garden mould suspension	84 % BOD/COD in 30 d 10 d window fulfilled readily biodegradable	2	Cognis (2001w) R-0100916
68439-57-6	**14-16**	**Na**	**OECD 301 B**	**Activated sludge**	**90 / 70 % ThCO$_2$ in 28 d 99 / 93 % DOC in 36 d 10 d window fulfilled readily biodegradable**	**1**	**Stepan Co. (1992)**
			OECD 301 D	**Activated sludge**	**78 % of ThOD in 28 d 14 d window fulfilled readily biodegradable**	**2**	**Kao Co. (1991)**
	Na (produced from lab-sulfonated pilot plant)		**Modified shake-flask**	**Secondary municipal waste water effluent, adapted**	**ca. 65 % CO_2 in 16 d ca. 98 % MBAS in 4 d readily biodegradable**	**2**	**Kravetz, Chung, and Rapean (1982)**
	Na (Olefin from Ziegler process)		**Modified shake-flask**	**Secondary municipal waste water effluent, adapted**	**ca. 65 % CO_2 in 16 d ca. 98 % MBAS in 4 d readily biodegradable**	**2**	**Kravetz, Chung, and Rapean (1982)**
863609-89-6	**14-18**	**Na**	**OECD 301 C**	**Activated sludge, non-adapted**	**BOD = 98 % in 15 d TOC = 98 % MBAS = 100 % readily biodegradable**		**Miura et al. (1979)**
			Modified shake-flask	**Secondary municipal waste water effluent, adapted**	**ca. 60 % CO_2 in 16 d ca. 98 % MBAS in 4 d readily biodegradable**	**2**	**Kravetz, Chung, and Rapean (1982)**
			OECD 301 D	garden mould suspension	82 % BOD/COD in 30 d readily biodegradable	2	Cognis (2001q) R-0100949
				Activated sludge, adapted	85.7 % COD in 8 d 99.4 % MBAS in 8 d	2	Pitter and Fuka (1979)
91722-28-0	16-18	Na	No data available				
99999-99-9	14/16/18	Na	No data available				

[1)] Reliability score specified in the IUCLID data sheet for each compound

ANNEX IV

Table IV-1 Aquatic Effects Endpoint - Acute Toxicity to Fish

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	LC_{50} [mg/l]	nominal vs. measured concentration	Reliability score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**Static**	**DIN 38412/15, deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg**	***Leuciscus idus***	**48 h**	**172**	**nominal**	**2**	**Cognis (2001a) R-0100603**
1072-15-7	9	Na	No data available							
142-87-0	**10**	**Na**	**Semistatic**	**OECD 203, 24 h renewal Hardness 250 mg $CaCO_3$/l**	***Danio rerio***	**96 h**	**177**	**nominal**	**2**	**Cognis (2001x) R-0100605**
			Static	**Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$**	***Cyprinus carpio prelarvae***	**48 h**	**13**	**measured**	**2**	**Kikuchi et al. (1976)**
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**Larval test, semistatic**	**24 h renewal, mixture of well water and carbon-filtered, demineralized tap water, hardness 193 - 210 mg/l $CaCO_3$**	***Pimephales promelas* (larvae)**	**7 d**	**2.3 (1 test) 4.6 (5 tests)**	**nominal**	**2**	**Pickering (1988)**
			Embryo-larval test, semistatic	**24 h renewal, mixture of well water and carbon-filtered, demineralized tap water, hardness 193 - 210 mg/l $CaCO_3$**	***Pimephales promelas* (embryo-larvae)**	**7 d**	**2.3 (5 tests) 4.6 (1 test)**	**nominal**	**2**	**Pickering (1988)**
			Flow-through	**Unfiltered river water**	***Pimephales promelas* (larvae)**	**42 d**	**> 1.36**	**measured**	**2**	**Belanger, Rupe, and Bausch (1995)**
			Flow-through	**Hardness 350 - 375 mg/l $CaCO_3$**	***Oncorhynchus mykiss* (juveniles)**	**10 d**	**2.85**	**nominal**	**2**	**Fogels & Sprague (1977)**
			Flow-through	**Hardness 350 - 375 mg/l $CaCO_3$**	***Danio rerio* (juveniles)**	**10 d**	**7.97**	**nominal**	**2**	**Fogels and Sprague (1977)**
			Flow-through	**Hardness 350 - 375 mg/l $CaCO_3$**	***Jordanella floridae* (juveniles)**	**10 d**	**6.9**	**nominal**	**2**	**Fogels and Sprague (1977)**
			Semistatic	**EPA-600/4-87/028, Seawater**	***Cyprinodon variegatus* (larvae)**	**7 d**	**2.9**	**nominal**	**2**	**Morrison et al. (1989)**
			Semistatic	**EPA-600/4-87/028, Seawater**	***Menidia beryllina* (larvae)**	**7 d**	**1.8**	**nominal**	**2**	**Morrison et al. (1989)**

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
			Static	**OECD 203**	***Leuciscus idus***	**48 h**	**25**	**nominal**	**4**	**Henkel KGaA (1999) R 9900955**
			Semistatic	**Japanese industrial standard (JIS) K 0102-1981, 12 h renewal hardness 25 mg/l $CaCO_3$**	***Oryzias latipes***	**48 h**	**46**	**nominal**	**2**	**Kikuchi and Wakabayashi (1984)**
			Semistatic	**Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$**	***Oryzias latipes***	**48 h**	**51**	**measured**	**2**	**Kikuchi et al. (1976)**
			Static	**Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$**	***Cyprinus carpio prelarvae***	**48 h**	**13**	**measured**	**2**	**Kikuchi et al. (1976)**
			Semistatic	**Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$**	***Cyprinus carpio eggs***	**96 h**	**18**	**measured**	**2**	**Kikuchi et al. (1976)**
			Static	**Spring water, Ca 8.55 mg/l, Mg 3.34 mg/l**	***Phoxinus phoxinus***	**24 h**	**30.5**	**nominal**	**2**	**Lundahl and Cabridenc (1978)**
			Static	**APHA 1971, Tap water, hardness 60-70 mg/l $CaCO_3$**	***Macrones vittatus***	**96 h**	**1.39**	**nominal**	**2**	**Verma, Mohan, and Dalela (1978)**
			Static	**APHA 1971, Tap water, hardness 60-70 mg/l $CaCO_3$**	***Macrones vittatus***	**96 h**	**1.53**	**nominal**	**2**	**Verma, Mohan, and Dalela (1978)**
			Static	**Artificial seawater**	***Cyprinodon variegatus***	**96 h**	**9**	**nominal**	**2**	**Anderson et al. (1974)**
			Static	**ASTM E-35, Seawater**	***Cyprinodon variegatus***	**96 h**	**4.1**	**nominal**	**2**	**Roberts et al. (1982)**
			Static	**ASTM E-35, Seawater**	***Menidia menidia***	**96 h**	**2.8**	**nominal**	**2**	**Roberts et al. (1982)**
			Static	**EPA 660/3-75-009 (1975), natural seawater**	***Menidia menidia***	**96 h**	**1.2**	**nominal**	**2**	**Hollister, Ward, and Parrish (1980)**
			Static	**Artificial seawater**	***Menidia beryllina***	**96 h**	**2.8**	**nominal**	**2**	**Anderson et al. (1974)**
			Static	**ASTM E729-88, Seawater**	***Menidia beryllina***	**96 h**	**1.48**	**nominal**	**2**	**Hemmer, Middaugh, and Comparetta (1992)**
			Static	**Artificial seawater**	***Fundulus similis***	**96 h**	**4.5**	**nominal**	**2**	**Anderson et al. (1974)**
			Static	**ASTM E729-88, Seawater**	***Atherinops affinis***	**96 h**	**1.88**	**nominal**	**2**	**Hemmer, Middaugh, and Comparetta (1992)**
				German Guideline	***Leuciscus idus melanotus***		**22**		**2**	**Juhnke and Luedemann (1978)**
			Flow-through	**EPA 660/3-75-009 (1975)**	***Lepomis macrochirus***	**96 h**	**4.5**	**measured**	**2**	**Bishop and Perry (1979)**
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
139-96-8	**12**	**TEA**	**no data available**							
3026-63-9	13	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	2.1	nominal	2	Cognis (2006a) R-0600045
1191-50-0	14	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	3.2	nominal	2	Cognis (2001c) R-0100606
			Semistatic	Japanese industrial standard (JIS) K 0102-1981, 12 h renewal, hardness 25 mg/l $CaCO_3$	*Oryzias latipes*	48 h	2.5	nominal	2	Kikuchi and Wakabayashi (1984)
			Semistatic	Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$	*Oryzias latipes*	24 h	5.9	measured	2	Kikuchi et al. (1976)
			Static	Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$	*Cyprinus carpio prelarvae*	48 h	5.0	measured	2	Kikuchi et al. (1976)
			Semistatic	Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$	*Cyprinus carpio eggs*	96 h	2.9	measured	2	Kikuchi et al. (1976)
13393-71-0	15	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	15	nominal	2	Cognis (2006c) R-0600047
1120-01-0	16	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	> 250	nominal	2	Cognis (2001d) R-0100607
			Semistatic	Japanese industrial standard (JIS) K 0102-1981, 12 h renewal, hardness 25 mg/l $CaCO_3$	*Oryzias latipes*	48 h	0.61	nominal	2	Kikuchi and Wakabayashi (1984)
			Semistatic	Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$	*Oryzias latipes*	48 h	0.50	measured	2	Kikuchi et al. (1976)
			Static	Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$	*Cyprinus carpio prelarvae*	48 h	0.69	measured	2	Kikuchi et al. (1976)
			Semistatic	Japanese industrial standard (JIS) K 0102, hardness 25 mg/l $CaCO_3$	*Cyprinus carpio eggs*	96 h	> 1.6	measured	2	Kikuchi et al. (1976)
7065-13-6	16	K	No data available							
1120-04-3	18	Na	Static	DIN 38412/15, deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	> 270	nominal	2	Cognis (2001f) R-0100609
90583-10-1	8-14	NH_4	Semistatic	ISO 7346 II , No data about origin and hardness	*Danio rerio*	96 h	5.3	measured	2	Henkel KGaA (1992j) 8248/404/1
85665-45-8	8-14	TEA	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	8.9	nominal	2	Cognis (2003d) R-0300640
90583-19-0	8-14	Li	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	7.3	nominal	2	Cognis (2003e) R-0300641
90583-27-0	8-16	Na	No data available							
68585-47-7	**10-16**	**Na**	**No data available**							
68081-97-0	10-16	Mg	No data available							
68081-96-9	**10-16**	**NH_4**	**No data available**							
117875-77-1	**10-16**	**TEA**	**No data available**							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	LC_{50} [mg/l]	nominal vs. measured concentration	Reliability score	References
68611-55-2	10-16		No data available							
91783-23-2	12-13	Na	No data available							
91783-22-1	12-13	K	No data available							
85586-07-8	**12-14**	**Na**	**Semistatic**	**OECD 203, 24 h renewal, Tap water, hardness 136 mg/l $CaCO_3$**	***Oncorhynchus mykiss***	**96 h**	**3.6**	**nominal**	**2**	**Kao (1996b) # 140/508**
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**Static**	**DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg**	***Leuciscus idus***	**48 h**	**9.2**	**nominal**	**2**	**Cognis (2001z) R-0100612**
90583-16-7	12-14	MEA	Semistatic	ISO 7346 II, No data about origin and hardness	*Danio rerio*	96 h	3.4	measured	2	Henkel KGaA (1992m) RE 910049
			Semistatic	OECD 203, demineralized water, hardness: 58 mg $CaCO_3$/l	*Danio rerio*	96 h	4.8	nominal	4	Stephan (1985)
90583-23-6	12-14	Mg	Semistatic	ISO 7346 II, Drinking water hardness: 250 mg $CaCO_3$/l	*Danio rerio*	96 h	7.9	nominal	2	Cognis (2001bb) R-0100614
68890-70-0	**12-15**	**Na**	**No data available**							
73296-89-6	**12-16**	**Na**	**Static**	**DIN 38412/15, deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg**	***Leuciscus idus***	**48 h**	**3.6**	**nominal**	**2**	**Cognis (2003f) R-0300642**
90583-12-3	**12-16**	**NH_4**	**No data available**							
68955-19-1	**12-18**	**Na**	**Static**	**DIN 38412/15, deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg**	***Leuciscus idus***	**48 h**	**9.3**	**nominal**	**2**	**Cognis (2004c) R-0400321**
90583-24-7	**12-18**	**K**	**No data available**							
99999-99-9	12-18	Mg	No data available							
90583-13-4	12-18	NH_4	Semistatic	ISO 7346 II, No data about origin and hardness	*Danio rerio*	96 h	2.8	measured	2	Henkel KGaA (1992k) 8253/404
86014-79-1	13-15	Na	No data available							
91648-54-3	14-15	Na	Semistatic	24 h renewal, Hardness: 171 - 320 mg/l $CaCO_3$	*Pimephales promelas*	96 h	0.81	nominal	2	Procter and Gamble (1998a) E-96-037
68081-98-1	**14-18**	**Na**	**No data available**							
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available							
90583-31-6	14-18 & 18 unsatd.	Na	Static	OECD 203, Deionized water, hardness: 14 dH°	*Oncorhynchus mykiss*	96 h	2.32	measured	2	Henkel KGaA (1992l) R-0000633
99999-99-9	15-16	Na	No data available							
68955-20-4	**16-18**	**Na**	**Semistatic**	**OECD 204, renewal 3 x per week**	***Danio rerio***	**14 d**	**1.65**	**nominal**	**2**	**Cognis (2001m) R-0100795**
			Semistatic	**OECD 203, 24 h renewal, Hardness: 250 mg/l $CaCO_3$**	***Danio rerio***	**96 h**	**5.2**	**nominal**	**2**	**Cognis (2001dd) R-0100616**

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
ALKANE SULFONATES										
HPV chemicals in bold										
5324-84-5	**8**	**Na**	**No data available**							
13419-61-9	10	Na	No data available							
2386-53-0	12	Na	No data available							
27175-91-3	14	Na	No data available							
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
30965-85-6	12	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	61	nominal	2	Cognis (2001r) R-0100965
93686-14-7	**14**	**Na**	**Static**	**JIS K 0102-1971, Tap water, dechlorinated, aerated, hardness: no data**	***Oryzias latipes***	**48 h**	**20**	**nominal**	**2**	**Lion Co. (1972a)**
11067-19-9	16	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	2.3	nominal	2	Cognis (2001s) R-0100966
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**Static**	**OECD 203, Deionized water, hardness 179 mg/l $CaCO_3$**	***Danio rerio***	**96 h**	**2.6**	**nominal**	**2**	**Kao Corp. (1992)**
			Semistatic	**Hardness 20 mg/l $CaCO_3$**	***Rasbora heteromorpha***	**96 h**	**3.3**	**nominal**	**2**	**Reiff et al. (1979)**
			Semistatic	**Hardness 26 - 30 / 250 mg/l $CaCO_3$**	***Salmo trutta***	**96 h**	**2.5 - 5.0**	**nominal**	**2**	**Reiff et al. (1979)**
			Semistatic / Static	**Hardness 150 / 268 mg/l $CaCO_3$**	***Idus idus***	**96 h**	**3.4 / 4.9**	**nominal**	**2**	**Reiff et al. (1979)**
863609-89-6	**14-18**	**Na**	**Semistatic**	**OECD 203, 24 h renewal, Tap water, aerated, hardness 70-30 mg/l $CaCO_3$**	***Oryzias latipes***	**96 h**	**0.5 - 1.2**	**nominal**	**2**	**Yoshioka, Ogino, and Mori (1995)**
			Static	**JIS K 0102-1971, Tap water, dechlorinated, aerated, hardness: no data**	***Oryzias latipes***	**48 h**	**1.4**	**nominal**	**2**	**Lion Corp. (1972b)**
			Semistatic	**JIS K 0102-1981, 24 h renewal, Hardness 25 mg/l $CaCO_3$**	***Oryzias latipes***	**48 h**	**1.8**	**nominal**	**2**	**Kikuchi and Wakabayashi (1984)**
99999-99-9	14/16/18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	Static	DIN 38412/15, Deionized water, hardness 16 dH, 93 mg/l Ca, 12 mg/l Mg	*Leuciscus idus*	48 h	1.2	nominal	2	Cognis (2001u) R-0100968
			Semistatic	JIS K 0102-1981, 12 h renewal, Hardness 25 mg/l $CaCO_3$	*Oryzias latipes*	48 h	0.81	nominal	2	Kikuchi and Wakabayashi (1984)

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
			Semistatic	Hardness 20 mg/l $CaCO_3$	*Rasbora heteromorpha*	96 h	0.5	nominal	2	Reiff et al. (1979)
			Semistatic	Hardness 26 - 30 mg/l $CaCO_3$	*Salmo trutta*	96 h	0.5	nominal	2	Reiff et al. (1979)
			Static	Hardness 268 mg/l $CaCO_3$	*Idus idus*	96 h	0.9	nominal	2	Reiff et al. (1979)

Table IV-2 Aquatic Effects Endpoint - Acute Toxicity to Aquatic Invertebrates

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_{50} LC_{50} [mg/l]	nominal vs. measured concentration	Reliability score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**Static**	**OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)**	***Daphnia magna***	**24 h**	**> 144**	**nominal**	**2**	**Cognis (2001b) R-0100604**
			Static	**AFNOR T.90301 (1974)**	***Daphnia magna***	**24 h**	**4 350**	**nominal**	**4**	**Lundahl and Cabridenc (1978)**
				Norme Francaise Homologue, 1983, NF T90-31	***Daphnia magna***	**24 h**	**> 900**	**nominal**	**4**	**Sanchez Leal et al. (1991)**
1072-15-7	9	Na	Static	AFNOR T.90301 (1974)	*Daphnia magna*	24 h	2 300	nominal	4	Lundahl and Cabridenc (1978)
142-87-0	**10**	**Na**	**Static**	**AFNOR T.90301 (1974)**	***Daphnia magna***	**24 h**	**800**	**nominal**	**4**	**Lundahl & Cabridenc (1978)**
				Norme Francaise Homologue, 1983, NF T90-31	***Daphnia magna***	**24 h**	**470**	**nominal**	**4**	**Sanchez Leal et al. (1991)**
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**Flow-through**	**Reconstituted water, hardness 114 - 205 mg/l $CaCO_3$**	***Ceriodaphnia dubia***	**48 h**	**5.55**	**measured**	**2**	**Dyer et al. (1997)**
			Static	**Reconstituted lake water, hardness 102 mg/l $CaCO_3$**	***Ceriodaphnia dubia***	**48 h**	**ca. 48**	**nominal**	**2**	**Cowgill and Milazzo (1991)**
			Static	**EPA 600/4-78-012 (1978), Synthetic hard water, hardness 160 - 180 mg/l $CaCO_3$, 20 °C, 26 °C**	***Daphnia magna***	**48 h**	**10.8 - 13.5**	**presumably nominal however with analytical monitoring**	**2**	**Lewis and Horning (1991)**
			Static	**Reconstituted well water, hardness 175 mg/l**	***Daphnia magna***	**48 h**	**7.8**	**nominal**	**2**	**LeBlanc (1982)**
			Static	**EPA 600/4-78-012 (1978), Synthetic hard water, hardness 160 - 180 mg/l $CaCO_3$**	***Daphnia magna***	**48 h**	**10.3**	**initial conc. measured**	**2**	**Lewis and Weber (1983)**
			Static	**OECD 202.1**	***Daphnia magna***	**24 h**	**29**	**nominal**	**4**	**Henkel KGaA (1999c) R 9900956**

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_{50} LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
			Static	84/449/EEC, Hardness 80 - 800 mg/l $CaCO_3$, 21 °C standard conditions (Hardness 250 mg/l $CaCO_3$, 20 °C)	*Daphnia magna*	24 h	9.6 - 39 27.5	nominal	2	Persoone et al. (1989)
			Static	AFNOR (1974)	*Daphnia magna*	24 h	9.8	nominal	2	Beaubien et al. (1986)
			Static	Hardness 286 mg/l	*Daphnia magna*	24 h	41	nominal	2	Bringmann and Kuehn (1982)
			Static	Hardness 16° dH	*Daphnia magna*	24 h	33	nominal	2	Bringmann and Kuehn (1977a)
			Static	AFNOR T.90301 (1974)	*Daphnia magna*	24 h	80	nominal	4	Lundahl and Cabridenc (1978)
				Norme Francaise Homologue, 1983, NF T90-31	*Daphnia magna*	24 h	25	nominal	4	Sanchez Leal et al. (1991)
			Flow-through	EPA 660/3-75-009 (1975)	*Daphnia magna*	48 h	1.8	measured	2	Bishop and Perry (1979)
			Static	EPA 600/4-78-012 (1978), Synthetic moderately hard water, hardness 80 - 90 mg/l $CaCO_3$, 20 °C, 26 °C	*Daphnia pulex*	48 h	10.2 - 12.6	presumably nominal however with analytical monitoring	2	Lewis and Horning (1991)
			Static	EPA 600/4-78-012 (1978), Synthetic moderately hard water, hardness 80 - 90 mg/l $CaCO_3$	*Daphnia pulex*	48 h	8.9	initial conc. measured	2	Lewis and Weber (1983)
			Static	Hardness 80 - 100 mg/l $CaCO_3$, EPA medium based on deionized water	*Branchionus rubens*	24 h	1.35	nominal	2	Snell and Persoone (1989b)
			Static	moderately hard synthetic freshwater medium according to US-EPA (1985)	*Branchionus calyciflorus*	24 h	1.4	nominal	2	Snell et al. (1991)
			Static	2-Day Life Cycle Test, well water, reverse osmosis water (50/50); hardness: 152.1 mg/l $CaCO_3$	*Brachionus calyciflorus*	48 h	1.45	measured	2	Versteeg et al. (1997); Procter and Gamble (1996) E92-029
			Static	2-Day Life Cycle Test	*Brachionus calyciflorus*	48 h	1.2	nominal	2	Radix et al. (1999)
			Static	Natural brackish water	*Nitocra spinipes*	96 h	14.4	nominal	2	Tarkpea, Hansson, and Samuelsson (1986)
			Static	ASTM E-729, Estuary water	*Neomysis americana*	96 h	7.24	nominal/ measured?	2	Roberts et al. (1982)
			Static	ASTM E-729, Estuary water	*Mysidopsis bahia*	96 h	6.62	nominal/ measured?	2	Roberts et al. (1982)
			Semistatic	APHA (1980), 24 h-renewal, Artificial seawater	*Mysidopsis bahia*	72 h	3.8 / 4.5	nominal	2	Tatem and Portzer (1985)

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_{50} LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
			Semistatic	EPA-600/4-87/028	*Mysidopsis bahia*	7 d	9.3	nominal	2	Morrison et al. (1989)
			Static	Artificial seawater	*Artemia salina*	48 h	3.15 - 3.8 (4 tests)	nominal	2	Zillioux et al. (1973)
			Static	Artificial seawater	*Artemia salina*	24 h	17.4 (9 tests)	nominal	2	Vanhaecke et al. (1980)
			Static	Artificial seawater	*Artemia salina*	24 h	20 (21 tests) - 22.52 (143 tests)	nominal	2	Vanhaecke and Persoone (1984)
			Static	Artificial seawater, variation of temperature, salinity, pH, DO, water quality (natural seawater)	*Artemia salina*	48 h	1.8 - 4.5 21.5	nominal	2	Gaonkar, Karande, and Rege (1986)
			Static	Artificial seawater, variation of temp. and salinity Standard conditions	*Artemia salina*	24 h	7.2 - 154	nominal	2	Persone et al. (1989)
			Static	Artificial seawater	*Artemia salina*	24 h	3.6	nominal	2	Price, Waggy, and Conway (1974)
			Static	According to Artoxkit (1990)	*Artemia salina*	24 h	41.04	nominal	2	Liwarska-Bizukojc et al. (2005)
			Static	Artificial seawater	*Mysidopsis almyra*	24 h	2.0	nominal	2	Anderson et al. (1974)
			Static	Artificial seawater	*Palaemonetes pugio*	96 h	108	nominal	2	Anderson et al. (1974)
			Static	Artificial seawater, variation of temp. and salinity	*Branchionus plicatilis*	24 h	10.9 - 29.4	nominal	2	Persoone et al. (1989)
			Static	Artificial seawater, variation ofsalinity	*Branchionus plicatilis*	24 h	4.42 - 5.42	nominal	2	Snell and Persoone (1989a)
			Semistatic	APHA (1980), renewal after 24 , Artificial seawater	*Acanthomysis sculpta*	72 h	0.94 / 0.96	nominal	2	Tatem and Portzer (1985)
			Static	Seawater	*Homarus americanus*	96 h	0.72	nominal	2	Wells and Sprague (1976)
				EPA-600/9-76-010	*Acartia tonsa*	96 h	0.12	nominal	2	Hollister, Ward, and Parrish (1980)
			Static	Multiwell test dishes	*Physa acuta*	24 h	27.2	nominal	2	Liwarska-Bizukojc et al. (2005)
			Static	EPA-600/4-87/028	*Arbacia punctulata*	1 h	3.2	nominal	2	Morrison et al. (1989)
			Static	EPA-600/4-87/028	*Arbacia punctulata*	80 min	0.37 - 3.19	nominal	2	Neiheisel and Young (1992)

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_{50} LC_{50} [mg/l]	nominal vs. measured concentration	Reliability score	References
			Flow-through		***Corbicula fluminea***	**5 d**	**16.7**	**measured**	**2**	**Graney and Giesey (1988)**
			Semistatic	**Dechlorinated tap water, hardness 35.6 mg/l $CaCO_3$**	***Limnaea peregra***	**6 d**	**≥ 0.606**	**measured**	**2**	**Tarazona and Nunez (1987)**
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							
139-96-8	**12**	**TEA**	**No data available**							
3026-63-9	13	Na	Static	OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)	*Daphnia magna*	24 h	4.2	nominal	2	Cognis (2006bb) R-0600046
			Static	AFNOR T.90301 (1974)	*Daphnia magna*	24 h	42	nominal	4	Lundahl and Cabridenc (1978)
1191-50-0	14	Na	Flow-through	Reconstituted water, hardness 114 - 205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	48 h	1.58	measured	2	Dyer et al. (1997)
			Static	2-Day Life Cycle Test, well water, reverse osmosis water (50/50); hardness: 152.1 mg/l $CaCO_3$	*Brachionus calyciflorus*	48 h	0.42	measured	2	Versteeg et al. (1997); Procter and Gamble (1996) E92-029
				Norme Francaise Homologue, 1983, NF T90-31	*Daphnia magna*	24 h	37	nominal	4	Sanchez Leal et al. (1991)
			Flow-through	Reconstituted water, hardness 114 - 205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	48 h	0.59	measured	2	Dyer et al. (1997)
13393-71-0	15	Na	No data available							
1120-01-0	16	Na	Flow-through	Reconstituted water, hardness 114 - 205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	48 h	0.15	measured	2	Dyer et al. (1997)
			Static	OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)	*Daphnia magna*	24 h	> 480 (no effect)	nominal	2	Cognis (2001e) R-0100608
7065-13-6	16	K	No data available							
1120-04-3	18	Na	Flow-through	Reconstituted water, hardness 114 - 205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	48 h	> 0.69 (no effect)	measured	2	Dyer et al. (1997)
			Static	OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)	*Daphnia magna*	24 h	> 98	nominal	2	Cognis (2001g) R-0100610
90583-19-0	8-14	Li	No data available							
90583-10-1	8-14	NH_4	Static	OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)	*Daphnia magna*	24 h	23	nominal	2	Cognis (2001y) R-0100611
85665-45-8	8-14	TEA	No data available							
90583-27-0	8-16	Na	No data available							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_{50} LC_{50} [mg/l]	nominal vs. measured concentration	Reliability score	References
68585-47-7	**10-16**	**Na**	**Static**	**National Guideline**	***Ceriodaphnia dubia***	**48 h**	**1.37**	**nominal**	**2**	**Warne and Schifko (1999)**
68081-97-0	10-16	Mg	No data available							
68081-96-9	**10-16**	**NH_4**	**No data available**							
117875-77-1	**10-16**	**TEA**	**No data available**							
68611-55-2	10-16		No data available							
91783-23-2	12-13	Na	No data available							
91783-22-1	12-13	K	No data available							
85586-07-8	**12-14**	**Na**	**Static**	**Synthetic river water**	***Daphnia magna***	**48 h**	**2.8**	**nominal**	**2**	**Lundahl, Cabridenc, and Xuereff (1973)**
90583-23-6	12-14	Mg	No data available							
90583-16-7	12-14	MEA	Static	OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)	*Daphnia magna*	24 h	14.7	nominal	2	Cognis (2004b) R-0400320
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**Static**	**OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)**	***Daphnia magna***	**24 h**	**38**	**nominal**	**2**	**Cognis (2001aa) R-0100613**
68890-70-0	**12-15**	**Na**	**No data available**							
73296-89-6	**12-16**	**Na**	**Static**	**OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)**	***Daphnia magna***	**24 h**	**18**	**nominal**	**2**	**Cognis (2001cc) R-0100615**
90583-12-3	**12-16**	**NH_4**	**No data available**							
68955-19-1	**12-18**	**Na**	**No data available**							
90583-24-7	**12-18**	**K**	**No data available**							
99999-99-9	12-18	Mg	No data available							
90583-13-4	12-18	NH_4	No data available							
86014-79-1	13-15	Na	No data available							
91648-54-3	14-15	Na	Flow-through	Reconstituted water, hardness 114 - 205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	48 h	0.8	measured	2	Dyer et al. (1997)
68081-98-1	**14-18**	**Na**	**No data available**							
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available							
90583-31-6	14-18 & 18 unsatd.	Na	No data available							
99999-99-9	15-16		No data available							
68955-20-4	**16-18**	**Na**	**No data available**							

ALKANE SULFONATES

HPV chemicals in bold

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_{50} LC_{50} [mg/l]	nominal vs. measured concentration	Relia-bility score	References
5324-84-5	**8**	**Na**	**Static**	**AFNOR T.90301 (1974)**	***Daphnia magna***	**24 h**	**3200**	**nominal**	**4**	**Lundahl and Cabridenc (1978)**
				Norme Francaise Homologue, 1983, NF T90-31	***Daphnia magna***	**24 h**	**> 900**	**nominal**	**4**	**Sanchez Leal et al. (1991)**
13419-61-9	10	Na		Norme Francaise Homologue, 1983, NF T90-31	*Daphnia magna*	24 h	350	nominal	2	Sanchez Leal et al. (1991)
2386-53-0	12	Na	Static	2-Day Life Cycle Test, well water, reverse osmosis water (50/50); hardness: 152.1 mg/l $CaCO_3$	*Brachionus calyciflorus*	48 h	6.5	measured	2	Versteeg et al. (1997); Procter and Gamble (1996) E92-029
			Static	AFNOR T.90301 (1974)	*Daphnia magna*	24 h	220	nominal	4	Lundahl and Cabridenc (1978)
				Norme Francaise Homologue, 1983, NF T90-31	*Daphnia magna*	24 h	135	nominal	4	Sanchez Leal et al. (1991)
27175-91-3	14	Na	Static	AFNOR T.90301 (1974)	*Daphnia magna*	24 h	60	nominal	4	Lundahl and Cabridenc (1978)
				Norme Francaise Homologue, 1983, NF T90-31	*Daphnia magna*	24 h	97	nominal	4	Sanchez Leal et al. (1991)
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
HPV chemicals in bold										
30965-85-6	12	Na	No data available							
93686-14-7	**14**	**Na**	**Static**	**OECD 202, Elendt M4 medium, hardness: 250 mg/l $CaCO_3$**	***Daphnia magna***	**48 h**	**14.4**	**measured**	**1**	**Lion Co. (2004d)**
11067-19-9	16	Na	Static	Screening method with deviations from OECD 202.1, Deionized water, hardness about 14 °dH (80 mg/l Ca and 12.2 mg/l Mg)	*Daphnia magna*	24 h	ca. 8.9	nominal	2	Cognis (2001t) R-0100967
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**Static**	**OECD 202.1, 50 % dechlorinated water, 50 % distilled water. Hardness: No data**	***Daphnia magna***	**48 h**	**3.48**	**nominal**	**2**	**Kao Co. (1993)**
			Static	**National Guideline**	***Ceriodaphnia dubia***	**48 h**	**4.53**	**nominal**	**2**	**Warne and Schifko (1999)**
863609-89-6	**14-18**	**Na**	**Semistatic**	**OECD 202, Tap water, aerated, hardness: 367 - 26 mg/l $CaCO_3$**	***Daphnia magna***	**24 h**	**7.1 - 19.2**	**nominal**	**2**	**Yoshioka, Ogino, and Mori (1995)**
99999-99-9	14/16/18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	No data available							

Table IV-3: Aquatic Effects Endpoint - Acute Toxicity to Algae / Aquatic Plants

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	Effect value [mg/l] [1)]	nominal vs. measured concentration	Relia-bility score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**No data available**							
1072-15-7	9	Na	No data available							
142-87-0	**10**	**Na**	**No data available**							
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**Static**	**Deonized water: hardness: 4.1 mg/l $CaCO_3$**	***Pseudokirchneriella subcapitata***	**96 h**	**E_rC_{50} = 117 E_rC_{10} = 12**	**nominal**	**2**	**Nyholm and Damgaard (1990)**
			Static	**Microtiter plates test based on ASTM E 1218-90, water chemistry not reported**	***Pseudokirchneriella subcapitata***	**72 h**	**Cell number: EC_{50} = 36.5 EC_{20} = 17.3**	**nominal**	**2**	**Procter and Gamble (2001) E98-048**
			Static	**OECD 201**	***Desmodesmus subspicatus***	**72 h**	**E_bC_{50} = 29 - 96**	**nominal**	**4**	**Henkel KGaA (1999j) R 9900957**
			Static	**DIN 38412, part 9**	***Desmodesmus subspicatus***	**72 h**	**$E_rC_{50} \geq 120$ E_bC_{50} = 53 NOEC = 30**	**measured**	**1**	**Henkel KGaA (1994b) R 9400430**
			Static	**OECD 201**	***Raphidocelis subcapitata***	**72 h**	**EC_{50} = 36.58**	**nominal**	**2**	**Liwarska-Bizukojc et al. (2005)**
			Static	**EPA-600/9-76-010**	***Skeletonema costatum***	**96 h**	**EC_{50} = 2.4**	**nominal**	**2**	**Hollister, Ward, and Parrish (1980)**
			Flow-through	**Well water, hardness 120-130 mg/l $CaCO_3$**	***Lemna minor***	**7 d**	**root length: EC_{50} = 18**	**measured**	**2**	**Bishop and Perry (1979)**
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							
139-96-8	**12**	**TEA**	**No data available**							
3026-63-9	13	Na	No data available							
1191-50-0	14	Na	No data available							
13393-71-0	15	Na	No data available							
1120-01-0	16	Na	No data available							
7065-13-6	16	K	No data available							
1120-04-3	18	Na	No data available							
90583-19-0	8-14	Li	No data available							

90583-10-1	8-14	NH_4	No data available						
85665-45-8	8-14	TEA	No data available						
90583-27-0	8-16	Na	No data available						
68585-47-7	**10-16**	**Na**	**Static**	**OECD 201, River water, fortified with nutrients, hardness: 150 mg/l $NaHCO_3$**	***Desmodesmus subspicatus***	**72 h**	**E_rC_{50} = 3.5 - 6.2 NOEC = 1.0**	**nominal**	**4**	**Kooijman, Hanstveit, and Oldersma (1983)**
			Static	**Synthetic medium**	***Pseudokirchneriella subcapitata***	**72 h**	**Cell number: EC_{50} = 60**	**nominal**	**2**	**Yamane, Okada, and Sudo (1984)**
68081-97-0	10-16	Mg	No data available						
68081-96-9	**10-16**	**NH_4**	**No data available**						
117875-77-1	**10-16**	**TEA**	**No data available**						
68611-55-2	10-16		No data available						
91783-23-2	12-13	Na	No data available						
91783-22-1	12-13	K	No data available						
85586-07-8	**12-14**	**Na**	**Static**	**OECD 201, medium AFNOR T-90 304**	***Pseudokirchneriella subcapitata***	**72 h**	**E_rC_{50} = 27**	**nominal**	**2**	**Verge and Moreno (1996)**
90583-23-6	12-14	Mg	No data available						
90583-16-7	12-14	MEA	No data available						
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**No data available**						
68890-70-0	**12-15**	**Na**	**No data available**						
73296-89-6	**12-16**	**Na**	**No data available**						
90583-12-3	**12-16**	**NH_4**	**No data available**						
68955-19-1	**12-18**	**Na**	**Static**	**OECD 201**	***Desmodesmus subspicatus***	**96 h**	**E_rC_{50} = 38 NOEC = 0.9**	**nominal**	**1**	**Henkel KGaA (1992g) RE 920281**
90583-24-7	**12-18**	**K**	**No data available**						
99999-99-9	12-18	Mg	No data available						
90583-13-4	12-18	NH_4	No data available						
86014-79-1	13-15	Na	No data available						
91648-54-3	14-15	Na	Static	EPA test method, artifical AAP medium	*Pseudokirchneriella subcapitata*	72 h	Cell number: EC_{50} = 4.63 EC_{10} = 1.56	nominal	2	Procter and Gamble (1986) 165-12-1100-2
			Static	OECD 201, fortified river water	*Desmodesmus subspicatus*	70 h	E_rC_{50} = 4.9 E_rC_{10} = 1.64 NOEC = 1.0 E_bC_{50} = 4.0 E_bC_{10} = 0.9	nominal	2	Procter and Gamble (1993d) IMW-92-0076-01
68081-98-1	**14-18**	**Na**	**No data available**						
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available						
90583-31-6	14-18 & 18 unsatd.	Na	No data available						

99999-99-9	15-16		No data available							
68955-20-4	**16-18**	**Na**	**Static**	**DIN 38412/9**	***Desmodesmus subspicatus***	**72 h**	**E_rC_{50} = 34**	**nominal**	**2**	**Cognis (2001ee) R-0100617**
ALKANE SULFONATES										
HPV chemicals in bold										
5324-84-5	**8**	**Na**	**No data available**							
13419-61-9	10	Na	No data available							
2386-53-0	12	Na	No data available							
27175-91-3	14	Na	No data available							
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
HPV chemicals in bold										
30965-85-6	12	Na	No data available							
93686-14-7	**14**	**Na**	**Static**	**OECD 201**	***Pseudokirchneriella subcapitata***	**72 h**	**E_rC_{50} = 81.8 E_bC_{50} = 42.3 NOEC = 12.8 (growth rate), < 5.9 (biomass)**	**measured**	**1**	**Lion Co. (2004e)**
11067-19-9	16	Na	No data available							
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**No data available**							
863609-89-6	**14-18**	**Na**	**Static**	**Synthetic medium**	***Pseudokirchneriella subcapitata***	**72 h**	**ErC_{50} = 45**	**nominal**	**2**	**Yamane, Okada, and Sudo (1984)**
99999-99-9	14/16/18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	No data available							

Table IV-4 Aquatic Effects Endpoint - Long-Term Toxicity to Fish

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Relia-bility score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**No data available**							
1072-15-7	9	Na	No data available							
142-87-0	**10**	**Na**	**No data available**							
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**No data available**							
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							
139-96-8	**12**	**TEA**	**No data available**							
3026-63-9	13	Na	No data available							
1191-50-0	14	Na	No data available							
13393-71-0	15	Na	No data available							
1120-01-0	16	Na	No data available							
7065-13-6	16	K	No data available							
1120-04-3	18	Na	No data available							
90583-19-0	8-14	Li	No data available							
90583-10-1	8-14	NH_4	No data available							
85665-45-8	8-14	TEA	No data available							
90583-27-0	8-16	Na	No data available							
68585-47-7	**10-16**	**Na**	**No data available**							
68081-97-0	10-16	Mg	No data available							
68081-96-9	**10-16**	**NH_4**	**No data available**							
117875-77-1	**10-16**	**TEA**	**No data available**							
68611-55-2	10-16		No data available							
91783-23-2	12-13	Na	No data available							
91783-22-1	12-13	K	No data available							
85586-07-8	**12-14**	**Na**	**No data available**							
90583-23-6	12-14	Mg	No data available							
90583-16-7	12-14	MEA	No data available							
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**No data available**							
68890-70-0	**12-15**	**Na**	**No data available**							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
73296-89-6	**12-16**	**Na**	**No data available**							
90583-12-3	**12-16**	**NH_4**	**No data available**							
68955-19-1	**12-18**	**Na**	**No data available**							
90583-24-7	**12-18**	**K**	**No data available**							
99999-99-9	12-18	Mg	No data available							
90583-13-4	12-18	NH_4	No data available							
86014-79-1	13-15	Na	No data available							
91648-54-3	14-15	Na	Early Life Stage Test, flow-through	well water, hardness: 22 - 30 mg/l $CaCO_3$	*Pimephales promelas*	34 d	0.11	measured	2	Procter and Gamble (1987) BW-87-2-2209
68081-98-1	**14-18**	**Na**	**No data available**							
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available							
90583-31-6	14-18 & 18 unsatd.	Na	No data available							
99999-99-9	15-16		No data available							
68955-20-4	**16-18**	**Na**	**No data available**							
ALKANE SULFONATES										
HPV chemicals in bold										
5324-84-5	**8**	**Na**	**No data available**							
13419-61-9	10	Na	No data available							
2386-53-0	12	Na	No data available							
27175-91-3	14	Na	No data available							
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
HPV chemicals in bold										
30965-85-6	12	Na	No data available							
936866-14-7	**14**	**Na**	**No data available**							
11067-19-9	16	Na	No data available							
	11-14	Na	Embryo larval test,, semistatic	Plate water	*Misgurnus fossilis* (Fertilized eggs)	until hatching plus 12 d	1.7	nominal	2	Lesyuk et al. (1983)

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
			semistatic	Spring and plain water	*Salmo gairdneri* (fingerlings)	25 d	1.7	nominal	2	Lesyuk et al. (1983)
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**No data available**							
863609-89-6	**14-18**	**Na**	**No data available**							
99999-99-9	14/16/18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	No data available							

Table IV-5: Aquatic Effects Endpoint: Long-term Toxicity to Aquatic Invertebrates

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**No data available**							
1072-15-7	9	Na	No data available							
142-87-0	**10**	**Na**	**Semistatic**	**Synthetic medium**	***Hydra attenuata***	**21 d (budding rate)**	**5.2**	**nominal**	**2**	**Bode, Ernst, and Arditti (1978)**
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**Flow-through**	**Reconstituted water, hardness: 114-205 mg/l $CaCO_3$**	***Ceriodaphnia dubia***	**7 d (reproduction)**	**0.88**	**measured**	**2**	**Dyer et al. (1997)**
			Semistatic	**Reconstituted lake water, hardness 94.4 mg/l $CaCO_3$**	***Ceriodaphnia dubia***	**3 (broods), ca. 6 d**	**9.36**	**nominal**	**2**	**Cowgill, Milazzo, and Landenberger (1990)**
			Semistatic	**Reconstituted lake water, hardness 102 mg/l $CaCO_3$**	***Ceriodaphnia dubia***	**3 (broods), ca. 7 d**	**ca. 30**	**nominal**	**2**	**Cowgill and Milazzo (1991)**
			Semistatic	**Reconstituted well water; hardness 175 mg/l $CaCO_3$**	***Daphnia magna***	**4 generat.**	**2.0 – 4.0**	**nominal**	**2**	**LeBlanc (1982)**
			Semistatic	**Synthetic medium**	***Hydra attenuata***	**21 d (budding rate)**	**5.8**	**nominal**	**2**	**Bode, Ernst, and Arditti (1978)**
			Flow-through	**Unfiltered river water**	***Corbicula fluminea***	**42 d (growth)**	**0.418**	**measured**	**2**	**Belanger, Rupe, and Bausch (1995)**
			Flow-through		***Corbicula fluminea***	**60 d (mortality)**	**3.0**	**measured**	**2**	**Graney and Giesey (1988)**
			Flow-through	**Unfiltered river water**	***Goniobasis* sp.**	**56 d (mortality, biomass)**	**≥ 1.357**	**measured**	**2**	**Belanger, Rupe, and Bausch (1995)**
			Flow-through	**Unfiltered river water**	***Limnephilus* sp.**	**56 d (mortality, emergence)**	**0.418**	**measured**	**2**	**Belanger, Rupe, and Bausch (1995)**
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							
139-96-8	**12**	**TEA**	**No data available**							
3026-63-9	12	Na	No data available							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
1191-50-0	14	Na	Flow-through	Reconstituted water, hardness: 114-205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	7 d **(reproduction)**	< 0.06	measured	2	Dyer et al. (1997)
			Semistatic	Synthetic medium	*Hydra attenuata*	21 d (budding rate)	63	nominal	2	Bode, Ernst, and Arditti (1978)
13393-71-0	15	Na	Flow-through	Reconstituted water, hardness: 114-205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	7 d (reproduction)	0.23	measured	2	Dyer et al. (1997)
1120-01-0	16	Na	Flow-through	Reconstituted water, hardness: 114-205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	7 d (reproduction)	0.20	measured	2	Dyer et al. (1997)
			Semistatic	Synthetic medium	*Hydra attenuata*	21 d (budding rate)	≥688	nominal	2	Bode, Ernst, and Arditti (1978)
7065-13-6	16	K	No data available							
1120-04-3	18	Na	Flow-through	Reconstituted water, hardness: 114-205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	7 d (reproduction)	0.60	measured	2	Dyer et al. (1997)
90583-19-0	8-14	Li	No data available							
90583-10-1	8-14	NH_4	No data available							
85665-45-8	8-14	TEA	No data available							
90583-27-0	8-16	Na	No data available							
68585-47-7	**10-16**	**Na**	**No data available**							
68081-97-0	10-16	Mg	No data available							
68081-96-9	**10-16**	**NH_4**	**No data available**							
117875-77-1	**10-16**	**TEA**	**No data available**							
68081-97-0	10-16		No data available							
91783-23-2	12-13	Na	No data available							
91783-22-1	12-13	K	No data available							
85586-07-8	**12-14**	**Na**	Semistatic	OECD 202	*Daphnia magna*	**21 d**	**EC_{50} = 5.7 mg/l**	**nominal**	**2**	**Verge and Moreno (2000)**
90583-23-6	12-14	Mg	No data available							
90583-16-7	12-14	MEA	No data available							
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**No data available**							
68890-70-0	**12-15**	**Na**	**No data available**							
73296-89-6	**12-16**	**Na**	**No data available**							
90583-12-3	**12-16**	**NH_4**	**No data available**							
68955-19-1	**12-18**	**Na**	**No data available**							
90583-24-7	**12-18**	**K**	**No data available**							
99999-99-9	12-18	Mg	No data available							
90583-13-4	12-18	NH_4	No data available							
86014-79-1	13-15	Na	No data available							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
91648-54-3	14-15	Na	Flow-through	fortified well water; hardness during test: 150-160 mg/l	*Daphnia magna*	21 d (reproduction)	0.05	measured	2	Procter and Gamble (1988) BW-87-10-2533
			Flow-through	Reconstituted water, hardness: 114-205 mg/l $CaCO_3$	*Ceriodaphnia dubia*	7 d (reproduction)	0.081	measured	2	Dyer et al. (1997)
68081-98-1	**14-18**	**Na**	**No data available**							
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available							
90583-31-6	14-18 & 18 unsatd.	Na	No data available							
99999-99-9	15-16		No data available							
68955-20-4	**16-18**	**Na**	**Semistatic**	**OECD 202**	***Daphnia magna***	**21 d**	**EC_{50} = 4.2 mg/l**	**nominal**	**2**	**Verge and Moreno (2000)**
ALKANE SULFONATES										
HPV chemicals in bold										
5324-84-5	**8**	**Na**	**No data available**							
13419-61-9	10	Na	No data available							
2386-53-0	12	Na	No data available							
27175-91-3	14	Na	No data available							
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
HPV chemicals in bold										
30965-85-6	12	Na	No data available							
93686-14-7	**14**	**Na**	**Semistatic**	**OECD 211, Elendt M4 medium, hardness: 250 mg/l $CaCO_3$, renewal 3 x/week**	***Daphnia magna***	**21 d**	**6.7**	**measured**	**1**	**Lion Co. (2004f)**
11067-19-9	16	Na	No data available							
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**No data available**							
863609-89-6	**14-18**	**Na**	**No data available**							
99999-99-9	14/16!18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	No data available							

Table IV-6: Toxicity to Microorganisms

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_0 or NOEC [mg/l]	nominal vs. measured concentration	Relia-bility score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**No data available**							
1072-15-7	9	Na	No data available							
142-87-0	**10**	**Na**	**No data available**							
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**Static**	**OECD (1976), respiration test**	**Activated sludge**	**30 min 3 h**	**EC_{50} = 188 / 135**	**nominal**	**2**	**Dutka, Nyholm, and Petersen (1983)**
			Static		**Synthetic activated sludge**	**3 h**	**IC_{50} = 480**	**nominal**	**2**	**Dutka and Kwan (1984)**
			Static	**DIN 38412, part 27**	***Pseudomonas putida***	**30 min**	**9050**	**nominal**	**4**	**Henkel KGaA (1999) R 9900959**
			Static	**DIN 38412, part 8**	***Pseudomonas putida***	**16 h**	**272**	**nominal**	**4**	**Henkel KGaA (1999) R 9900958**
			Static	**Cell multiplication inhibition test**	***Pseudomonas putida***	**16 h**	**290**	**nominal**	**2**	**Bringmann and Kuehn (1976, 1977b)**
			Static	**Cell multiplication inhibition test**	***Entosiphon sulcatum***	**72 h**	**40 [1)]**	**nominal**	**2**	**Bringmann (1978)**
			Static	**Cell multiplication inhibition test**	***Uronema parduczi***	**20 h**	**0.75 [1)]**	**nominal**	**2**	**Bringmann and Kühn (1980)**
			Static	**Cell multiplication inhibition test**	***Chilomonas paramaecium***	**48 h**	**26 [1)]**	**nominal**	**2**	**Bringmann, Kuehn, and Winter (1980)**
				Cell multiplication	***Podospora anserina***	**5 d**	**EC_{50} = 110**	**nominal**	**2**	**Lysek and Witsch (1974)**
			Static	**Damage of cells**	***Rhizobium meliloti***	**20 min**	**EC_{50} = 28**	**nominal**	**2**	**Botsford et al. (1997)**
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							
139-96-8	**12**	**TEA**	**No data available**							
3026-63-9	13	Na	No data available							
1191-50-0	14	Na	No data available							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_0 or NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
13393-71-0	15	Na	No data available							
1120-01-0	16	Na	No data available							
7065-13-6	16	K	No data available							
1120-04-3	18	Na	No data available							
90583-19-0	8-14	Li	No data available							
90583-10-1	8-14	NH_4	No data available							
85665-45-8	8-14	TEA	No data available							
90583-27-0	8-16	Na	No data available							
68585-47-7	**10-16**	**Na**	**No data available**							
68081-97-0	10-16	Mg	No data available							
68081-96-9	**10-16**	**NH_4**	**No data available**							
117875-77-1	**10-16**	**TEA**	**No data available**							
68611-55-2	10-16		No data available							
91783-23-2	12-13	Na	No data available							
91783-22-1	12-13	K	No data available							
85586-07-8	**12-14**	**Na**	**No data available**							
90583-23-6	12-14	Mg	No data available							
90583-16-7	12-14	MEA	Static	DIN 38412, part 27,proposal	*Pseudomonas putida*	30 min	≥ 3050	nominal	1	Henkel KGaA (1991m) RE 910057
			Static	DIN 28412, part 8, proposal	*Pseudomonas putida*	16 h	915	nominal	1	Henkel KGaA (1991n) RE 910131
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**Static**	**DIN 38412, part 27**	***Pseudomonas putida***	**30 min**	**4290**	**nominal**	**4**	**Henkel KGaA (1999i) R 9900954**
			Static	**DIN 38412, part 8**	***Pseudomonas putida***	**16 h**	**429**	**nominal**	**4**	**Henkel KGaA (1999h) R 9900953**
68890-70-0	**12-15**	**Na**	**Static**	**anaerobic**	**Anaerobic bacteria**	**3 d**	**EC_{10} = 188 mg/l**	**nominal**	**2**	**Shell (1992a)**
73296-89-6	**12-16**	**Na**	**No data available**							
90583-12-3	**12-16**	**NH_4**	**No data available**							
68955-19-1	**12-18**	**Na**	**Static**	**DIN 38412, part 27**	***Pseudomonas putida***	**30 min**	**≥ 90**	**nominal**	**2**	**Henkel KGaA (1993a) RE 930134**
				DIN 38412, part 27	***Pseudomonas putida***	**30 min**	**≥ 3940**	**nominal**	**2**	**Henkel KGaA (1995d) 8252/427/1**
90583-24-7	**12-18**	**K**	**No data available**							
99999-99-9	12-18	Mg	No data available							
90583-13-4	12-18	NH_4	No data available							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	EC_0 or NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
86014-79-1	13-15	Na	No data available							
91648-54-3	14-15	Na	No data available							
68081-98-1	**14-18**	**Na**	**No data available**							
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available							
90583-31-6	14-18, 18=	Na	Static	DIN 38412, part 27	*Pseudomonas putida*	30 min	300	nominal	1	Henkel KGaA (1993c) RE 930115
99999-99-9	15-16		No data available							
68955-20-4	**16-18**	**Na**	**No data available**							
ALKANE SULFONATES										
HPV chemicals in bold										
5324-84-5	**8**	**Na**	**no data available**							
13419-61-9	10	Na	No data available							
2386-53-0	12	Na	No data available							
27175-91-3	14	Na	No data available							
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
HPV chemicals in bold										
30965-85-6	12	Na	No data available							
936866-14-7	**14**	**Na**	**No data available**							
11067-19-9	16	Na	No data available							
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**No data available**							
863609-89-6	**14-18**	**Na**	**No data available**							
99999-99-9	14/16/18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	No data available							

[1]) EC_5

Table IV-7: Aquatic Effects Endpoint: Multispecies Tests

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
ALKYL SULFATES										
HPV chemicals in bold										
142-31-4	**8**	**Na**	**No data available**							
1072-15-7	9	Na	No data available							
142-87-0	**10**	**Na**	**No data available**							
7739-63-1	10	K	No data available							
39943-70-9	10	TEA	No data available							
99999-99-9	11	K	No data available							
151-21-3	**12**	**Na**	**Microcosm study, flow-through**	**Well water, hardness 225 - 278 mg/l $CaCO_3$, indoor**	**Natural periphyton communities**	**28 d**	**0.055 (cell density and biovolume, 1 of 12 taxa**	**measured**	**2**	**Belanger et al. (1996)**
			Mesocosm study; flow-through	**P&G stream facility, River water; hardness 120-190 mg/l $CaCO_3$, outdoor**	**Macroinvertebrates, multiple species**	**56 d**	**0.224 (indirect effects: increase of total invertebrate density due to increased heterophobic periphyton biomass)**	**measured**	**2**	**Belanger, Meiers, and Bausch (1995)**
			Mesocosm study, flow-through	**P&G stream facility, River water, outdoor**	**Invertebrates, multiple species**	**56 d**	**0.061 (due to nutritional-related responses)**	**measured**	**4**	**Procter and Gamble (1995b) E91-009**
			Mesocosm study; flow-through	**P&G stream facility, River water; hardness 120-190 mg/l $CaCO_3$, outdoor**	**Microorganisms, multiple species**	**56 d**	**>1.59 : autotrophic activity 0.582 : heterotrophic activity 0.224 : Protozoan taxa richness**	**measured**	**2**	**Guckert (1996)**
			Mesocosm study; flow-through	**P&G stream facility, River water; hardness 120-190 mg/l $CaCO_3$, outdoor**	**Protistan communities**	**55 d**	**EC_{20} = 0.063 (increase of protozoan species richness)**	**nominal**	**2**	**McCormick, Belanger, and Cairns (1997)**
4706-78-9	12	K	No data available							
2235-54-3	**12**	**NH_4**	**No data available**							
139-96-8	**12**	**TEA**	**No data available**							
3026-63-9	13	Na	No data available							
1191-50-0	14	Na	No data available							
13393-71-0	15	Na	No data available							
1120-01-0	16	Na	No data available							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Reliability score	References
7065-13-6	16	K	No data available							
1120-04-3	18	Na	No data available							
90583-19-0	8-14	Li	No data available							
90583-10-1	8-14	NH_4	No data available							
85665-45-8	8-14	TEA	No data available							
90583-27-0	8-16	Na	No data available							
68585-47-7	**10-16**	**Na**	**No data available**							
68081-97-0	10-16	Mg	No data available							
68081-96-9	**10-16**	**NH_4**	**No data available**							
117875-77-1	**10-16**	**TEA**	**No data available**							
68611-55-2	10-16		No data available							
91783-23-2	12-13	Na	No data available							
91783-22-1	12-13	K	No data available							
85586-07-8	**12-14**	**Na**	**No data available**							
90583-23-6	12-14	Mg	No data available							
90583-16-7	12-14	MEA	No data available							
90583-18-9 (96690-75-4)	**12-14**	**TEA**	**No data available**							
68890-70-0	**12-15**	**Na**	**No data available**							
73296-89-6	**12-16**	**Na**	**No data available**							
90583-12-3	**12-16**	**NH_4**	**No data available**							
68955-19-1	**12-18**	**Na**	**No data available**							
90583-24-7	**12-18**	**K**	**No data available**							
99999-99-9	12-18	Mg	No data available							
90583-13-4	12-18	NH_4	No data available							
86014-79-1	13-15	Na	No data available							
91648-54-3	14-15	Na	Mesocosm study; flow-through	P&G stream facility, River water; hardness 120-190 mg/l $CaCO_3$, outdoor	131 algal and 133 invertebrates species	56 d	0.222 population level NOEC for 3 of 264 species	measured	2	Procter and Gamble (2002) E97-016 Belanger et al. (2004)
68081-98-1	**14-18**	**Na**	**No data available**							
85681-68-1	14-18 & 16-18 unsatd.	Na	No data available							
90583-31-6	14-18, 18=	Na	No data available							
99999-99-9	15-16		No data available							
68955-20-4	**16-18**	**Na**	**No data available**							

Test Substance CAS No.	Chain Length	Counter Ion	Test Type	Test Conditions	Species	Exposure Period	NOEC [mg/l]	nominal vs. measured concentration	Relia-bility score	References
ALKANE SULFONATES										
HPV chemicals in bold										
5324-84-5	**8**	**Na**	**No data available**							
13419-61-9	10	Na	No data available							
2386-53-0	12	Na	No data available							
27175-91-3	14	Na	No data available							
13893-34-0	18	Na	No data available							
68815-15-6	15-18	Na	No data available							
α-OLEFIN SULFONATES										
HPV chemicals in bold										
30965-85-6	12	Na	No data available							
936866-14-7	**14**	**Na**	**No data available**							
11067-19-9	16	Na	No data available							
85536-12-5	12-14	Na	No data available							
68439-57-6	**14-16**	**Na**	**No data available**							
863609-89-6	**14-18**	**Na**	**No data available**							
99999-99-9	14/16/18	Na	No data available							
91082-14-3	15-18	Na	No data available							
91722-28-0	16-18	Na	No data available							

ANNEX V: USE AND EXPOSURE INFORMATION

Purpose

- To provide high end to bounding estimates of the potential environmental and human exposure to the chemicals of the Alkyl Sulfates Chemical Category from its manufacture and its use in consumer products in the United States, Europe, and Japan to complement an OECD SIDS Programme review of this category.

Coverage

The report covers exposure from manufacturing and consumer use for the volumes of surfactants of this category produced and used in the United States (U.S.), Europe, and Japan.

Synthesis of Key Assessment Results

The chemicals of this category contain three classes of anionic surfactants: Alkylsulfates with a predominantly linear alkyl chain length of C_8 - C_{18}, one alkane sulfonate and α-olefin sulfonates with linear aliphatic chains of typically C_{14} - C_{18}. The surfactants of this category are produced, transported as either pure solids or as water solutions, typically at a 22 - 70 % activity level. 21 of the 61 chemicals included in this category have HPV status in one or more OECD regions.

About 102 000 tonnes alkyl sulfates are consumed in Europe (HERA, 2002). According to CEH (2004), in 2003 totally 118 000 t/a were consumed in the USA and Canada, 105 000 t/a in Western Europe, and 11 500 t/a in Japan. The chemicals of this category are anionic surfactants that are used at active concentrations between 3 and 5 % in consumer cleaning and personal care products, usually in conjunction with other surfactants. They function as laundry and liquid dishwashing detergents, dispersing agents, hard surface cleaners, shampoos, hair conditioners, liquid soaps, cleansing and other personal care products.

There are no commercial or industrial process intermediate uses of the chemicals of this category. The predominant disposal route following use of the products that contain chemicals of this category is via wastewater.

The Anionic Surfactants are water soluble (at least those substances with chain length up to C_{16}) and have very low volatility. They are nearly completely disposed down the drain. Residual chemicals of this category entering the environment are rapidly and completely biodegraded. Their bioaccumulation potential is low up to a carbon chain length of C_{16} (BCF < 100). The chemicals of this category are readily biodegradable under aerobic conditions and are effectively removed during wastewater sewer transport and in biological wastewater treatment. These characteristics help to minimize the potential for human and environmental exposure.

The $PNEC_{aqua}$ for alkyl sulfates was determined to range from 4.5 µg/l (as a "worst case") to 88 µg/l ("best case"). For α-olefin sulfonates, the lowest effect value is a 96 h-LC_{50} of 0.5 mg/l. The $PNEC_{aqua}$ for AOS was determined to be 0.5 µg/l.

Analytical measurements of alkyl sulfates revealed that the concentration in effluents of waste water treatment plants are generally below 10 µg/l. In the receiving surface waters, most of the available values are below 5 µg/l, with a maximum of 10.2 µg/l.

The most appropriate NOAEL is 100 mg/kg/day from a 90-day repeated dose study. Modeled estimates of environmental concentrations leading to indirect human exposure from drinking water range from $4.6 \cdot 10^{-5}$ to $2.0 \cdot 10^{-4}$ and total food uptake range from $3.38 \cdot 10^{-3}$ (C_{18}) to $6.88 \cdot 10^{-6}$ (C_{13}) mg/kg/day. The results of the dermal exposure modeling for consumer uses of products containing surfactants category range from $2.3 \cdot 10^{-2}$ to $2.3 \cdot 10^{-5}$ mg/kg/day. Inhalation modeling of spray products indicates an estimated exposure of $3.0 \cdot 10^{-5}$ mg/kg/day.

All exposure evaluations include conservative (protective) input assumptions (using worst case estimates for duration and use frequency).

These results indicate that the aquatic and human hazard levels are not reached under current conditions of manufacturing, use, and disposal.

Identity of Organization	Anionic Surfactants Consortium
(rsedlak@sdahq.org)	**The Soap and Detergent Association, c/o Richard Sedlak** 1500 K St. NW, Suite 300, Washington, DC 20005

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Format A: General Information

I. Substance information

(1) Category name

Alkyl Sulfates, C_8 Alkane Sulfonate and C_{14-16} Alpha Olefin Sulfonate - Chemical Category

(2) Substance Name(s) and CAS RN

139-96-8	Sulfuric acid, mono-dodecyl ester, compd. with triethanolamine (1:1) (C_{12} ASO_4 TEA)
142-31-4	Sulfuric acid, mono-octyl ester, sodium salt (C_8 ASO_4 Na)
142-87-0	Sulfuric acid, mono-decyl ester, sodium salt (C_{10} ASO_4 Na)
151-21-3	Sulfuric acid, mono-dodecyl ester, sodium salt (C_{12} ASO_4 Na)
1072-15-7	n-Nonylsulfate, sodium salt (C_9 ASO_4 Na)
1120-01-0	Sulfuric acid, mono-hexadecyl ester, sodium salt (C_{16} ASO_4 Na)
1120-04-3	Sulfuric acid, mono-octadecyl ester, sodium salt(C_{18} ASO_4 Na)
1191-50-0	Sulfuric acid, mono-tetradecyl ester, sodium salt(C_{14} ASO_4 Na)
2235-54-3	Sulfuric acid, mono-dodecyl ester, ammonium salt (C_{12} ASO_4 NH_4)
2386-53-0	Sodium dodecane-1-sulfonate (C_{12} ASO_3 Na)
3026-63-9	1-Tridecanol, hydrogen sulfate, sodium salt (C_{13} ASO_4 Na)
4706-78-9	Potassium dodecyl sulphate (C_{12} ASO_4 K)
5324-84-5	1-Octanesulfonic acid, sodium salt (C_8 ASO_3 Na)
7065-13-6	Potassium hexadecyl sulphate (C_{16} ASO_4 K)
7739-63-1	Potassium decyl sulphate (C_{10} ASO_4 K)
11067-19-9	Sodium hexadecene-1-sulfonate (C_{16} =/$OHASO_3$ Na)
13393-71-0	Sulfuric acid, mono-pentadecyl ester, sodium salt (C_{15} ASO_4 Na)
13419-61-9	Sodium decane-1-sulfonate (C_{10} ASO_3 Na)
13893-34-0	Sodium octadecane-1-sulfonate (C_{18} ASO_3 Na)
27175-91-3	Sodium tetradecane-1-sulfonate (C_{14} ASO_3 Na)
30965-85-6	Dodecene-1-sulfonic acid, sodium salt (C_{12} =/$OHASO_3$ Na)
39943-70-9	Sulfuric acid, monodecyl ester, compd. with 2,2',2"-nitrilotris[ethanol] (1:1) (C_{10} ASO_4 TEA)
68081-96-9	Sulfuric acid, mono-C_{10-16}-alkyl esters, ammonium salts (C_{10-16} ASO_4 NH_4)
68081-97-0	Sulfuric acid, mono-C_{10-16}-alkyl esters, magnesium salts (C_{10-16} ASO_4 Mg)
68081-98-1	Sulfuric acid, mono-C_{14-18}-alkyl esters, sodium salts (C_{14-18} ASO_4 Na)
68439-57-6	Sulfonic acids, C_{14-16}-alkane hydroxy and C_{14-16}-alkene, sodium salts (C_{14-16} =/$OHASO_3$ Na)
68585-47-7	Sulfuric acid, mono-C_{10-16}-alkyl esters, sodium salts (C_{10-16} ASO_4 Na)
68611-55-2	Sulfuric acid, mono-C_{10-16}-alkyl esters (C_{10-16} ASO_4)
68815-15-6	Sulfonic acids, C_{15-18}-alkane, sodium salts (C_{15-18} ASO_3 Na)
68890-70-0	Sulfuric acid, mono-C_{12-15}-alkyl esters, sodium salts (C_{12-15} ASO_4 Na)
68955-19-1	Sulfuric acid, mono-C_{12-18}-alkyl esters, sodium salts (C_{12-18} ASO_4 Na)
68955-20-4	Sulfuric acid, mono-C_{16-18}-alkyl esters, sodium salts (C_{16-18} ASO_4 Na)
73296-89-6	Sulfuric acid, mono-C_{12-16}-alkyl esters, sodium salts (C_{12-16} ASO_4 Na)
85536-12-5	Sulfonic acids, C_{12-14}-alkane hydroxy and C_{12-14}-alkene, sodium salts (C_{12-14} =/$OHASO_3$ Na)
85586-07-8	Sulfuric acid, mono-C_{12-14}-alkyl esters, sodium salts (C_{12-14} ASO_4 Na)
85665-45-8	Sulfuric acid, mono-C_{8-14}-alkyl esters, compounds with triethanolamine (C_{8-14} ASO_4 TEA)
85681-68-1	Sulfuric acid, mono-(C_{14-18} and C_{16-18} –unsatd.alkyl) esters, sodium salts (C_{14-18} and C_{16-18}= ASO_4 Na)
86014-79-1	Sulfuric acid, mono-C_{13-15}-alkyl esters, sodium salts (C_{13-15} ASO_4 Na)
90583-10-1	Sulfuric acid, mono-C_{8-14}-alkyl esters, ammonium salts (C_{8-14} ASO_4 NH_4)
90583-12-3	Sulfuric acid, mono-C_{12-16}-alkyl esters, ammonium salts (C_{12-16} ASO_4 NH_4)
90583-13-4	Sulfuric acid, mono-C_{12-18}-alkyl esters, ammonium salts (C_{12-18} ASO_4 NH_4)
90583-16-7	Sulfuric acid, mono-C_{12-14}-alkyl esters, compounds with ethanolamine (C_{12-14} ASO_4 MEA)
90583-18-9	Sulfuric acid, mono-C_{12-14}-alkyl esters, compounds with triethanolamine (C_{12-14} ASO_4 TEA)
90583-19-0	Sulfuric acid, mono-C_{8-14}-alkyl esters, lithium salts (C_{8-14} ASO_4 Li)
90583-23-6	Sulfuric acid, mono-C_{12-14}-alkyl esters, magnesium salts (C_{12-14} ASO_4 Mg)
90583-24-7	Sulfuric acid, mono-C_{12-18}-alkyl esters, potassium salts (C_{12-18} ASO_4 K)
90583-27-0	Sulfuric acid, mono-C_{8-16}-alkyl esters, sodium salts (C_{8-16} ASO_4 Na)
90583-31-6	Sulfuric acid, mono-(C_{14-18} and $C_{18\text{-unsaturated}}$)-alkyl esters, sodium salts (C_{14-18} and $C_{18=}$ ASO_4 Na)

91082-14-3	Sulfonic acids, C_{15-18}-alkane hydroxy and C_{15-18}-alkene, sodium salts (C_{15-18} =/$OHASO_3$ Na)
91648-54-3	Sulfuric acid, mono-C_{14-15}-alkyl esters, sodium salts (C_{14-15} ASO_4 Na)
91722-28-0	Sulfonic acids, C_{16-18}-alkane hydroxy and C_{16-18}-alkene, sodium salts (C_{16-18} =/$OHASO_3$ Na)
91783-22-1	Sulfuric acid, mono-C_{12-13}-alkyl esters, potassium salts (C_{12-13} ASO_4 K)
91783-23-2	Sulfuric acid, mono-C_{12-13}-alkyl esters, sodium salts (C_{12-13} ASO_4 Na)
93686-14-7	Sulfonic acids, C_{14}-alkane hydroxy and C_{14}-alkene, sodium salts (C_{14} =/$OHASO_3$ Na)
96690-75-4	Sulfuric acid, mono-C_{12-14}-alkyl esters, ammonium salts, compds. with triethanolamine (C_{12-14} ASO_4 TEA)
117875-77-1	Sulfuric acid, mono-C_{10-16}-alkyl esters, compounds with triethanolamine (C_{10-16} ASO_4 TEA)
863609-89-6	Sulfonic acids, C_{14-18}-alkane hydroxy and C_{14-18}-alkene, sodium salts (C_{14-18} =/$OHASO_3$ Na)
99999-99-9	Sulfuric acid, mono-C_{15-16}-alkyl esters (C_{15-16} ASO_4)
99999-99-9	Sulfuric acid, mono-C_{12-18}-alkyl esters, magnesium salts (C_{12-18} ASO_4 Mg)
99999-99-9	Potassium undecyl sulphate (C_{11} ASO_4 K)
99999-99-9	Sulfonic acids, $C_{14/16/18}$-alkane hydroxy and $C_{14/16/18}$-alkene, sodium salts (1:1:1) ($C_{14/16/18}$ =/$OHASO_3$ Na)

(3) Substance Formula and Structure

This category contain three structurally related classes of anionic surfactants: The alkylsulfates are sulfate salts with predominantly linear alkyl chains (typically C_8 - C_{16}) of a single chain length or a defined chain length distribution, bearing a terminal, sulfate ester anion, neutralized with a base. One alkane sulfonate is included in the category, which is the salt of a linear carbon chain (C_8), bearing a terminal sulfonate anion, neutralized with sodium hydroxide. Alpha Olefin Sulfonates are furthermore included in this category. They are mixtures of sodium alkene sulfonate and hydroxyl alkane sulfonate salts, with the sulfonate group in the terminal position and the double bond, or hydroxyl group, located at various positions along the linear aliphatic chain (typically C_{14} - C_{16}). The anionic surfactants are salts or complexes consisting of a hydrophobic, hydrocarbon chain (of varying chain length), with a terminal, polar, sulfur-containing anion, neutralized with a base-derived cation or an amine (e.g. sodium cation, ammonium cation or triethanolamine).

(4) Physical Form

The chemicals of this category exist as either pure solids or as aqueous solutions with a content of active substance between 23 and 90 %.

(5) Other Constituents

Impurities such as, ammonium, sodium, potassium chlorides, or sulfates may be present. Depending on the method of manufacture, trace levels of stabilizers, processing aids or other impurities may be present.

II. Summary

(1) Data Collection Efforts

Information in this assessment was assembled from a number of sources:

1) Member company surveys of the Anionic Surfactants Consortium (including producers representing the majority of Anionic Surfactants production in the U.S.), the U.S. Soap and Detergent Associations (SDA), the European CESIO were used to collect data on Anionic Surfactants production volumes, uses, releases, and potential exposures. To protect proprietary information, an independent third party compiled the resulting data.

2) An environmental risk assessment on alkyl sulfates exist as a HERA report (HERA, 2002), where appropriate data are compiled. These data include also monitoring data of the alkyl sulfates. The CAS numbers compiled in this documentation are: 139-96-8, 142-31-4, 142-87-0, 151-21-3, 1120-01-0, 1120-04-3, 1191-50-0, 2235-54-3, 68081-96-9, 68081-98-1, 68130-43-8, 68140-10-3, 68412-83-9, 68585-47-7, >, 68890-70-0, 68995-19-1, 68955-20-4, 73296-89-6, 85338-42-7, 85586-07-8, 85586-38-5, 85665-45-8, 85681-68-1, 86014-79-1, 90583-10-1, 90583-12-3, 90583-13-4, 90583-16-7, 90583-18-9, 90583-19-0, 90583-23-6, 90583-27-0, 90583-31-6, 91648-54-3, 91783-23-2, 92797-61-0, 96690-75-4, 117875-77-1.

3) A Human Health Risk Assessment exists in terms of a HERA report on the alcohol sulfates (HERA, 2002). The CAS numbers compiled in this documentation are: 139-96-8, 142-87-0, 151-21-3, 1120-01-0,

1120-04-3, 1191-50-0, 2235-54-3, 68081-96-9, 68081-98-1, 68130-43-8, 68140-10-3, 68412-83-9, 68585-47-7, 68611-55-2, 68890-70-0, 68995-19-1, 68955-20-4, 73296-89-6, 85338-42-7, 85586-38-5, 85665-45-8, 85681-68-1, 86014-79-1, 90583-10-1, 90583-12-3, 90583-13-4, 90583-16-7, 90583-18-9, 90583-19-0, 90583-23-6, 90583-27-0, 90583-31-6, 91648-54-3, 91783-23-2, 92797-61-0, 96690-75-4, 117875-77-1.
Direct exposures from consumer uses of products containing chemicals of this category are examined using general exposure models for four exposure scenarios: 1) use of washing powder 2) use of diluted and undiluted liquid detergents (hand-wash of dishes, laundry pre-treatment, and hand-wash of laundry) and diluted and undiluted hard surface cleaning products; 3) exposure to laundry product residue on clothing (liquid laundry detergents); 4) exposure to personal care products during and after use. Specific product data for the CAS-Nos indicated above are only compiled for the US market. It is assumed, that the concentrations of the chemicals of this categoryAnionic Surfactants are similar in products present on the European and the Japanese market.

(2) Discussion of Key Uncertainties, Limitations, Data Gaps

a) Consumer exposures are addressed for all known product category uses in the USA.

b) This exposure assessment takes a conservative (protective) approach to modeling, selecting inputs based on conservative values and worst case estimates for frequency and duration of tasks; thus modeled estimates are likely to significantly exceed actual exposures. For predicted environmental exposures, this is supported by a comparison of monitoring results to modeling estimates. For consumer exposure, actual dermal absorption is below 1 % (Rice, 1977) or very low (Schäfer and Redelmeier, 1996), therefore all modeled exposures include a default assumption of 1 %.

c) A few minor consumer use scenarios are not modeled: hand wash with dishwashing liquid, as it is assumed, that laundry pre-treatment represents a similar exposure; teeth brushing (no default values available)

d) The following additional approaches have been made:
Exposure to facial cleaners: A percent retention on the skin of 100 % was assumed
Exposure to baby washes soap: A frequency of 1 was assumed, and the amount of 16100 mg was used (analogous to body washes)
Exposure to hand and face soap: The amount given for the bar soap was used

(3) Exposure Results
The following tables show the estimated exposure for the scenarios assessed, and the NOECs (derived for the Alkyl sulfates, HERA or NOAEL (derived for this category) hazard values.

Environmental Exposure Scenarios

Exposure Scenario	Concentration (µg/L)	Aquatic NOEC (µg/L)
Measured Surface Water Concentrations		
United States (Surface water)	< 5	C_{12} - 880 C_{13} - 200 C_{14} - 45 C_{15} - 230 C_{16} - 204 C_{18} - 602
United States (estimated from effluent conc.)	C_{12}: 4.6, C_{13}: 1.2, C_{14}: 3.9, C_{15}: 4.3	
Netherlands (effluent in activated sludge plants.)	C_{12}-C_{15}: 1.2 - 12	
Modelling Emissions of estimated European Tonnages		
Aquatic Exposure - 102 000 tonnes/a		
C_{12}	2.12	C_{12} - 880
C_{13}	0.78	C_{13} - 200
C_{14}	1.17	C_{14} - 45
C_{15}	0.24	C_{15} - 230
C_{16}	1.36	C_{16} - 204
C_{18}	0.56	C_{18} - 602

Consumer Exposure Scenarios

Exposure Scenario	Estimated Exposure (mg/kg/day)	NOAEL (mg/kg/day)
Indirect Exposure-Average daily dose local		
Drinking Water Consumption	$2.0 \cdot 10^{-4}$	100
Total Food Uptake		
C_{12}	$3.22 \cdot 10^{-4}$	
C_{13}	$1.46 \cdot 10^{-4}$	
C_{14}	$8.26 \cdot 10^{-5}$	
C_{15}	$3.96 \cdot 10^{-5}$	
C_{16}	$9.55 \cdot 10^{-4}$	
C_{18}	$3.38 \cdot 10^{-3}$	
Indirect Exposure-Average daily dose regional		
Drinking Water Consumption	$4.6 \cdot 10^{-5}$	100
Total Food Uptake		
C_{12}	$1.32 \cdot 10^{-5}$	
C_{13}	$6.88 \cdot 10^{-6}$	
C_{14}	$2.84 \cdot 10^{-5}$	
C_{15}	$1.33 \cdot 10^{-5}$	
C_{16}	$6.90 \cdot 10^{-5}$	
C_{18}	$4.59 \cdot 10^{-4}$	
Dermal Modeling		
Cleaning Products		
Filling of washing machine (powder)	negligible	100
Laundry pre-treatment (undiluted)	$4.9 \cdot 10^{-4}$	
Hand-wash of laundry (diluted)	$3.7 \cdot 10^{-5}$	
Hand dishwashing (diluted)	$4.7 \cdot 10^{-4}$	
Hard surface cleaner (diluted)	$4.0 \cdot 10^{-5}$	
Hard surface cleaner (undiluted)	$2.9 \cdot 10^{-5}$	
Laundry product residual on clothing		
Liquid detergent	$1.3 \cdot 10^{-4}$ to $1.7 \cdot 10^{-4}$	100

Personal Care product residual after use		
Liquid soap - hand	$1.8 \cdot 10^{-4}$*	100
Liquid soap - face	$2.3 \cdot 10^{-5}$*	
Shampoo	$1.1 \cdot 10^{-3}$ to $1.4 \cdot 10^{-3}$	
Hair conditioner	$3.4 \cdot 10^{-4}$	
Body washes	$2.1 \cdot 10^{-3}$ to $2.7 \cdot 10^{-3}$	
Facial cleaner	$2.3 \cdot 10^{-2}$	
Baby bath soap	$6.4 \cdot 10^{-3}$**	
Inhalation Modeling		
Spray cleaner	$3.0 \cdot 10^{-5}$	100

*) The amount (g/use) values for the soap bar are used.
**) Frequency 1, and the amount of the body washes is used for calculation

The dermal exposures are also summarized below aggregated by product category use. The aggregation was accomplished by simple addition of the modeled exposures within a product category, e.g., the three modeled scenarios for liquid detergent exposures - hand-washing, pre-treatment, and residual on clothing).

Product Type	Estimated Exposure (mg/kg/day)	NOAEL (mg/kg/day)
Laundry Detergent - Liquid	$6.6 \cdot 10^{-4}$ to $7.0 \cdot 10^{-4}$	100
Hard Surface Cleaner - Liquid	$6.9 \cdot 10^{-5}$	
Liquid Soap	$2.0 \cdot 10^{-4}$	
Hair Care	$1.4 \cdot 10^{-3}$ to $1.7 \cdot 10^{-3}$	

III. Production, Import and Use

(1) Estimated Volume (tonnes/year)
Alkyl sulfates:

Total use in Europe: 102 000 t/a (CESIO statistics, 1999, cited in HERA, 2002)
European use in household detergents: 65 000 t/a (CESIO statistics, 1999, cited in HERA, 2002)

Consumption by world region (CEH, 2004):

World Region	Heavy-duty laundry powders	Heavy-duty laundry liquids	Light-duty powders and liquids	Other uses *
USA and Canada	92	-	-	26
Western Europe	43	22	5	35
Japan	3.0	1.5		7

*: includes personal care products and industrial, institutional and commercial uses

Alkane sulfonates:
Consumption in Western Germany: 16 000 t/a in 1986 (Schoeberl et al., 1988)

Alpha-Olfenin sulfonates:

Consumption in Western Europe: 6 000 t in 2003 (CEH, 2004)
Consumption in Japan: 3 000 t in 2003 (CEH, 2004)

(2) Function/ Product Use Categories

The alkyl sulfates are used as laundry detergents, dispersing agents in manufacturing, dishwashing products, additives for plastics and paints, cosmetics and personal care products. Minor uses are the following applications in food: emulsifier, whipping agent, surfactant in fruit drinks, wetting agent in crude vegetable oils and animal fats, or a use in adhesives, cellophane, paper and paperboard, coatings, closures, rubber articles and textiles.

The alkane sulfonates are used in surfactant mixtures for shampoos and foam bath products (Biermann, 1987), and in liquid detergents (e.g. washing-up liquids) often in conjunction with alkyl ether sulfates (AES) and in concentrated shampoos, in textile and leather auxiliaries (mercerising), preparations for cleaning metal, steam jets and pickling baths (Painter, 1992).

In the USA almost all AOS was used in personal care products and industrial applications (amount not reported). In Western Europe, the major use was in industrial and institutional cleaners with some small quantities used in light-duty liquids (specifically wool detergents) and personal care products. In Japan, the major use was in household detergents, and small volumes are currently used in personal care products (i.e. shampoo) (CEH, 2004).

IV. Activities, Releases and Exposures - Factors that Mitigate or Exacerbate Exposures

Manufacture

(1) Process Description

Alkyl sulfates: Commercial alkyl sulfates are produced by sulfation of detergent range, primary alcohols using sulfur trioxide or chlorosulfonic acid followed by neutralisation with base (sodium hydroxide, ammonia, or alkanolamines such as triethanolamine) to produce the corresponding salt.

Alkane sulfonates: Alkane sulfonates are produced by sulfoxidation, sometimes still by sulfochlorination of unbranched paraffins. Today the Light-Water-Process is commonly used. SO_2 and O_2 and paraffin/water are irradiated by UV light at 30 - 40 °C. The reaction is limited to 1 - 5 % yield to avoid formation of di- and oligo sulfonates. The process is performed continuously; alkane sulfonates are continuously separated from the reaction mixture.

α-Olefins: Commercial alpha olefin sulfonates are produced by reaction of sulfur trioxide with linear α-olefins followed by neutralisation and hydrolysis of sultone intermediates with sodium hydroxide.

(2) General Description of Potential Releases and Exposures

Potential workplace exposure includes dermal contact with the liquid; there is the potential for incidental or accidental ingestion, and/or eye contact with the liquid product during handling in the manufacturing process.

(3) Discussion of Factors that Mitigate or Exacerbate Releases and Exposures

During production, manufacturing, storage, transport and transfer processes no intended release of the chemicals of the Anionic Surfactants group into the environment will occur. Only in case of accidents the product may be released into the environment. Environmental releases of chemicals of the Anionic Surfactants group are not regulated independently, but they are regulated as part of overall facility emissions. Engineering controls (e.g., closed system operation, exhaust ventilation, dust collection) and personal protective equipment (e.g., protective clothing, eyewear, and gloves) at facilities that manufacture and formulate anionic surfactants mitigate worker exposure and no special engineering controls or additional personal protective equipment are uniquely specified for the Anionic Surfactants.

(4) Remarks

Product formulation or other types of secondary manufacture is not expected to result in environmental or workplace exposures that exceed those for Anionic Surfactants manufacturing facilities.

Industrial Use

(5) Function/Product Use Description

(6) General description of Potential Releases and Exposures

(7) Discussion of Factors that Mitigate or Exacerbate Releases and Exposures

(8) Remarks: The chemicals of the Anionic Surfactants Category are manufactured for use in consumer and commercial/institutional product formulation and are not used as intermediates/derivatives for further chemical manufacturing processes.

Commercial Use

(9) Function/Product Use Description

Product Type	Concentration in Products
Shampoo	5 %
Face and Hand Soaps (liquid)	5 %

The concentrations are given for products on the North American market. It is assumed, that the concentrations of Anionic Surfactants in commercial use products on the European or Asian market are similar.

(10) General description of Potential Releases and Exposures

The products may be used as they are or they may be diluted with water prior to use. Dermal exposure will occur during use of the products There is some potential for incidental or accidental ingestion of, and/or eye contact with products during handling and use. Environmental releases from down-the-drain discharges following product use may lead to potential environmental exposures in surface waters and indirect human exposures via drinking water and/or fish consumption. These potential exposures are discussed in the following pages and quantified with modeling data (Format C).

(11) Discussion of Factors that Mitigate or Exacerbate Releases and Exposures

Exposure to chemicals of this category in Commercial Products is mitigated by following use and precaution instructions on product labels. Product labels reflect the hazard potential of the chemical ingredients in the product. For example products may include eye irritancy warnings along with instructions to rinse thoroughly if eye exposure occurs.

Dermal exposure to chemicals of this category in Commercial Products is mitigated by the fact that dermal penetration of the substances is usually below 1 %. The exposure scenarios given in this document are calculating with a dermal absorption of 100 %, the percentage of systemically available anionic surfactants is therefore overestimated with a factor of 100.

Regarding environmental release the exposure of the chemicals of this category is mitigated by effective removal during wastewater transport and treatment plants. As Anionic Surfactants are highly water soluble and have very low volatility, they are nearly completely disposed down the drain. Residual chemicals of this category entering the environment are rapidly and completely biodegraded. Their bioaccumulation properties are very low. These characteristics help to minimize the potential for environmental and human exposure.

(12) Remarks:

Consumer Use

(13) Function/ Product Use Description

The chemicals of this group have widespread and dispersive use as surfactants in the following consumer products.

Product Type	Concentration in Products
Laundry	
Laundry powder (solid)	4 %
Prewashes (liquid)	5 %
Cleaning	
General Cleaners (liquid/dilutable)	4 %
Hard Surface Cleaner (liquid)	3 - 4 %
Personal Care	
Shampoo	4 - 5 %
Hair Conditioner	5 %
Face and Hand Soaps (liquid)	5 %
Facial Cleaners	4 %
Body Washes	4 - 5 %
Cosmetics	
Tooth Paste (Paste)	4 %
Baby Care	
Baby Bath Soap (liquid)	4 %

The concentrations are given for products on the North American market. It is assumed, that the concentrations of this substances in commercial use products on the European or Asian market are similar.

(14) General Description of Direct Exposures to Consumer Products and of Potential Releases to the Environment Leading to Environmental Exposures and Indirect Human Exposures

Laundry, cleaning, and personal care products may be used as is, or diluted prior to or during use. Dermal contact will occur with these products. There is some potential for incidental or accidental ingestion of, inhalation of, and/or eye contact with products during handling and use. Environmental releases from down-the-drain discharges following product use may lead to potential environmental exposures in surface waters and indirect human exposures via drinking water and/or fish consumption. These potential exposures are discussed in the following pages and quantified with monitoring (Format B) and modeling data (Format C).

(15) Discussion of Factors that Mitigate or Exacerbate Releases and Exposures

Exposure to chemicals of the Anionic Surfactants category in formulated consumer laundry, cleaning and personal care products is mitigated by following use and precaution instructions on product labels. Product labels reflect the hazard potential of the chemical ingredients in the product. These product labels also include first aid instructions to accompany each hazard warning. For example, products may include eye and skin irritancy warnings along with instructions to rinse thoroughly if dermal or other exposure occurs.

Human exposure is mitigated by the fact that residues from many of these products are washed or rinsed off. Also, actual dermal absorption is below 1 % (Rice, 1977) or very low (Schäfer and Redelmeier, 1996), therefore all modeled exposures include a default assumption of 1 %.

Anionic Surfactants are highly water soluble (between 0.5 and 400 000 mg/l) and have very low volatility ($\leq 3 \cdot 10^{-7}$ hPa at 25 °C). Consumer products containing chemicals of the Anionic Surfactants are disposed of down-the-drain where it is effectively removed during wastewater transport and treatment plants. Residual Anionic Surfactants entering the environment are rapidly biodegraded. Based on determined bioaccumulation factors in fish, the potential for bioaccumulation in aquatic organisms is low, at least for the C_{12} - C_{16} alkyl sulfate sodium salts (BCF < 100). These characteristics help to minimize the potential for environmental and human exposure.

(16) Remarks:

References (Annex V Use and exposure information)

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