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PFAS and alternatives

Environment and Health Issues

Allan Astrup Jensen

Research Director

Nordic Institute of Product Sustainability, Environmental Chemistry and Toxicology

Allan.astrup.jensen@gmail.com

Polyfluoroalkyl substances (PFAS)

- This are synthetic chemicals used in many industrial processes and in consumer products exposing the public.

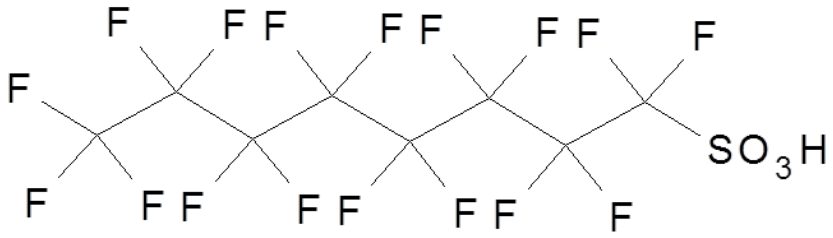
- Among the most well-known uses are for production of “Teflon” pans, impregnation of microwave popcorn bags and children's all-weather clothing.

Polyfluoroalkyl substances (PFAS)

PFAS are surface-active compounds (surfactants) with extremely low surface tensions, and they repel water, fat and dirt. Therefore, they are very much used for impregnation of leather and textile furniture:

The most important PFAS is PFOS?

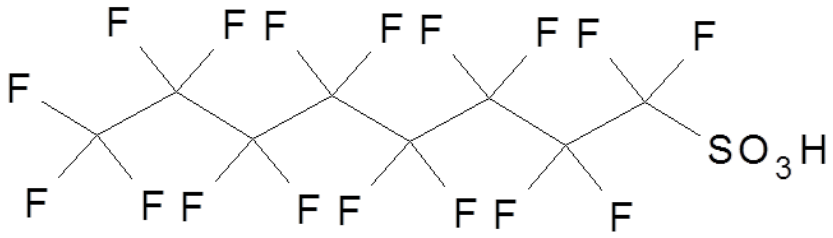
PFOS is: Perfluorooctane sulfonic acid and its salts

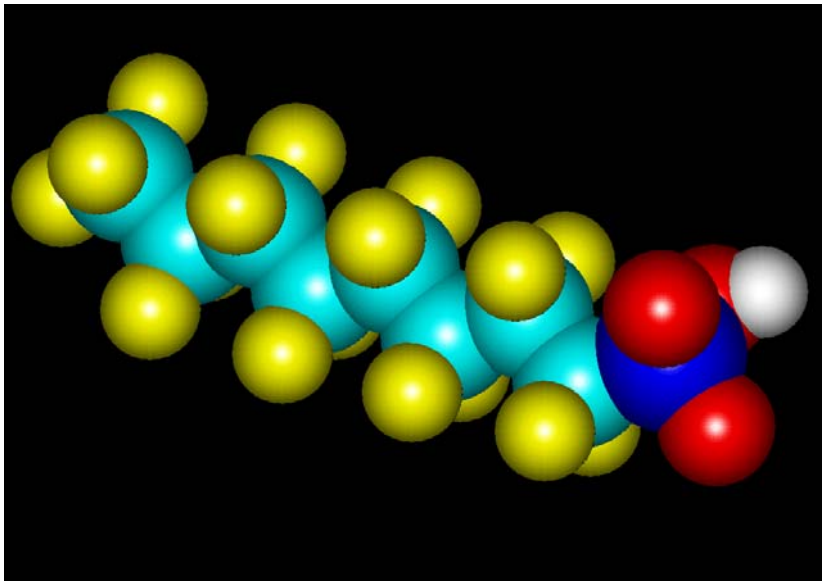


$C_8HF_{17}SO_3$

The most important PFAS is PFOS?

PFOS is: Perfluorooctane sulfonic acid and its salts



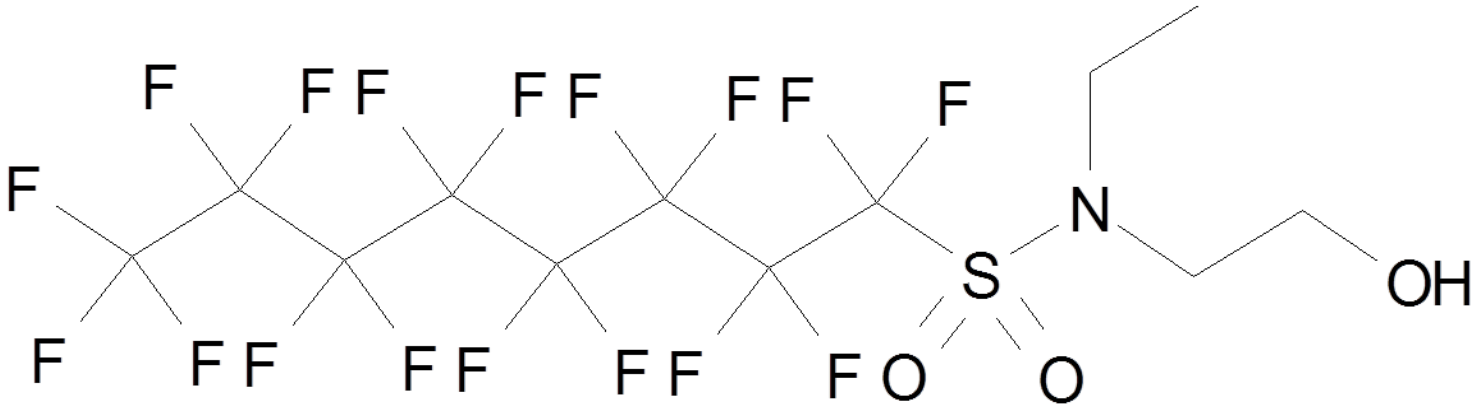


$C_8HF_{17}SO_3$

PFOS is also far the most hazardous PFAS!

PFOS precursors

The PFOS substances mostly used in practice are functional derivatives of the basic chemical structure e.g. substituted sulfonamides:



N-Ethylperfluorooctane sulfonamidoethanol; EtFOSE

PFOS precursors

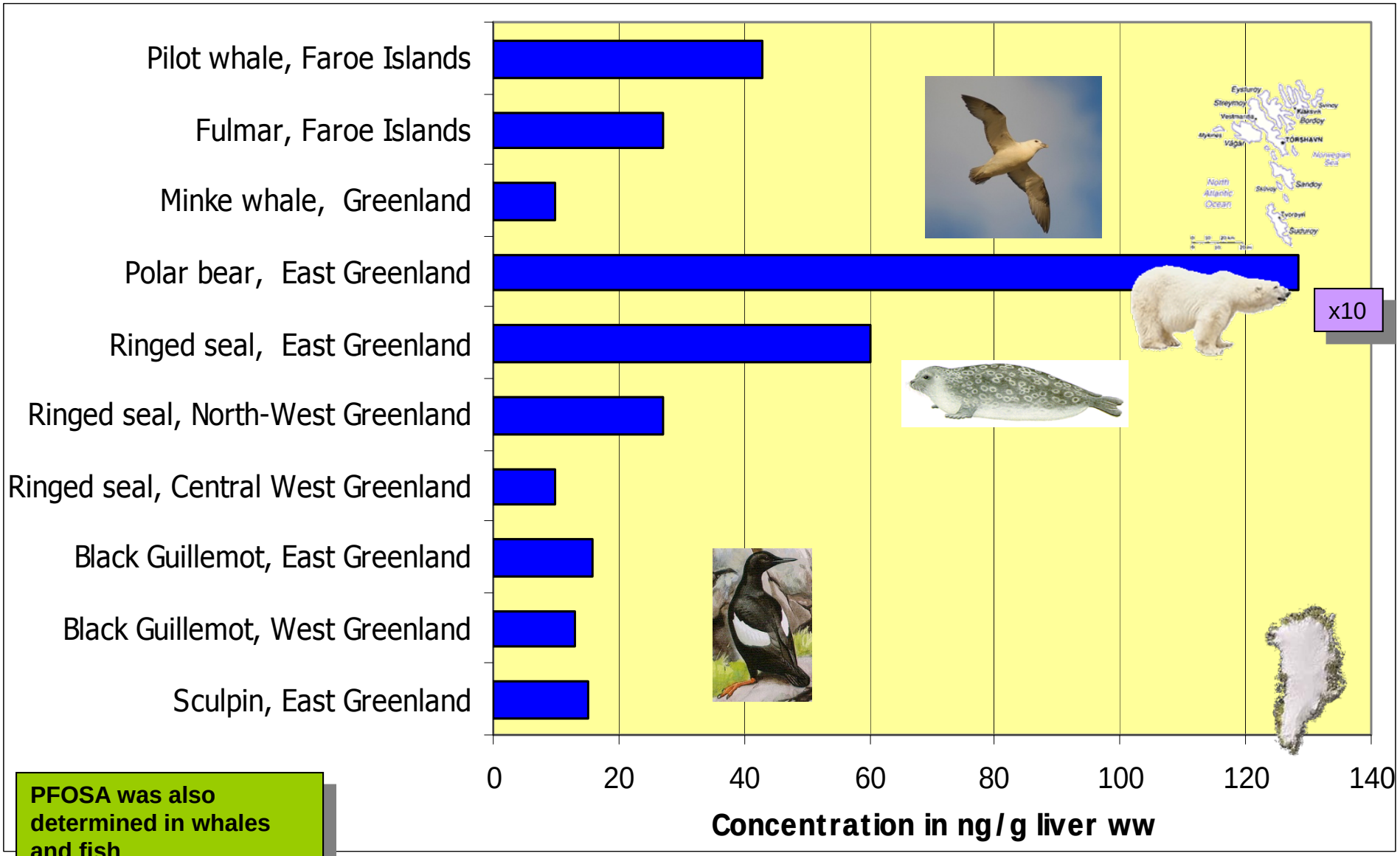
- These PFOS derivatives are more biodegradable but only to PFOS, because the fluorinated tail will never degrade in nature; homologue compounds with shorter or longer chain behave similarly.

- While PFOS and its salts with a hydrophilic functional group are non-volatile and will be spread with surface waters, the covalent amides are more volatile and may be transported over long distances to remote areas by the air.

PFOS in the environment

- PFOS is persistent, bioaccumulating and toxic
- It is found wide spread in nature, organisms and humans
- The highest levels have been found in blood and livers from polar bears.

PFOS in biota from Greenland and Faroe Islands



PFOSA was also determined in whales and fish

(Bossi et al. 2005)

PFOS production

- 3M Company located in Minnesota, USA, did voluntarily stop the production of PFOS in 2002, because of discoveries of PFOS in Polar bears.

- 3M changed to produce PFCs with a shorter C_4-alkyl chain, which have a much lower potential for toxicity and accumulation in animals and Man - but still are persistent.

- These substances can substitute PFOS in most applications.

- However, PFOS is in stead produced in China (200 tons in 2006).

- The total accumulated World production of PFOS and derivatives has been around 100.000 tons.

Regulations

- Most uses of perfluorooctane sulfonic acid (PFOS) and its derivatives have been banned in all OECD countries but some uses such as
  - photoresist or anti-reflective coatings for photolithography processes,
  - industrial photographic coating,
  - mist suppressants for chromium plating and other electroplating applications, and
  - aviation hydraulic fluids;

  are, however, still allowed because of lack of recognized good alternatives.

- In 2009 PFOS was included in the list of POPs in the Stockholm Convention with even more exemptions and acceptable uses

PFOS derivatives mentioned in the Stockholm Convention

PFOS substance	CAS no.
Perfluorooctane sulfonic acid	1763-23-1
Potassium perfluorooctane sulfonate	2795-39-3
Lithium perfluorooctane sulfonate	29457-72-5
Ammonium perfluorooctane sulfonate	29081-56-9
Diethanolammonium perfluorooctane sulfonate	70225-14-8
Perfluorooctane sulfonyl fluoride	307-35-7
Tetraethylammonium perfluorooctane sulfonate	56773-42-3
Di(decyl)di(methyl)ammonium perfluorooctane sulfonate	2551099-16-8

Examples of PFOS derivatives/precursors not specifically mentioned in the Stockholm Convention

Chemical name	Acronym	CAS no.
Perfluorooctane sulfonamide	PFOSA	754-91-6
N-Methyl perfluorooctane sulfonamide	MeFOSA	31506-32-8
N-Methyl perfluorooctane sulfonamidoethanol	MeFOSE	2448-09-7
N-Methyl perfluorooctane sulfonamidoethyl acrylate	MeFOSEA	25268-77-3
Ammonium bis[2-*N*-ethyl perfluorooctane sulfonamidoethyl] phosphate		30381-98-7
N-Ethyl perfluorooctane sulfonamide (sulfluramid)	EtFOSA	4151-50-2
N-Ethyl perfluorooctane sulfonamidoethanol	EtFOSE	1691-99-2
N-Ethyl perfluorooctane sulfonamidoethyl acrylate	EtFOSEA	432-82-5
Di[*N*-ethyl perfluorooctane sulfonamidoethyl] phosphate	EtFOSEP	67969-69-1
3-[[(Heptadecafluorooctyl)- sulfonyl]amino]-*N,N,N*-trimethyl-1-propanaminium iodide/perfluorooctyl sulfonyl quaternary ammonium iodide	Fluorotenside -134	1652-63-7
Potassium *N*-ethyl-*N*-[(heptadecafluorooctyl) sulfonyl] glycinate		2991-51-7
N-Ethyl-*N*-[3-(trimethoxysilyl)propyl] perfluorooctane sulfonamide		61660-12-6

Many other polyfluorinated substances

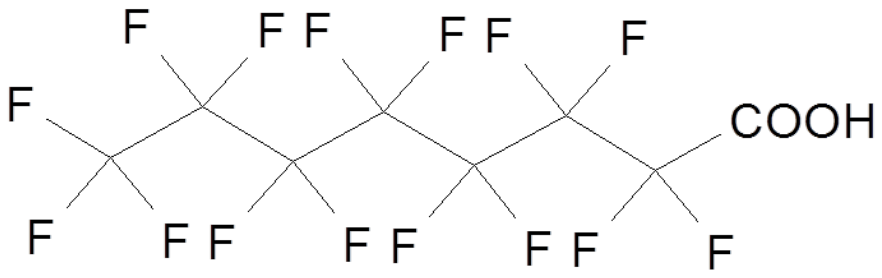
- In 2006 OECD listed almost 1000 different polyfluorinated substances.

- In 2008 we found many of these in products on the Danish market, however we also found substances not included in the OECD list.

- A search in our national Product Registry showed that 92 different polyfluorinated substances were in use and of these 11 had a consumption of >100 kg:

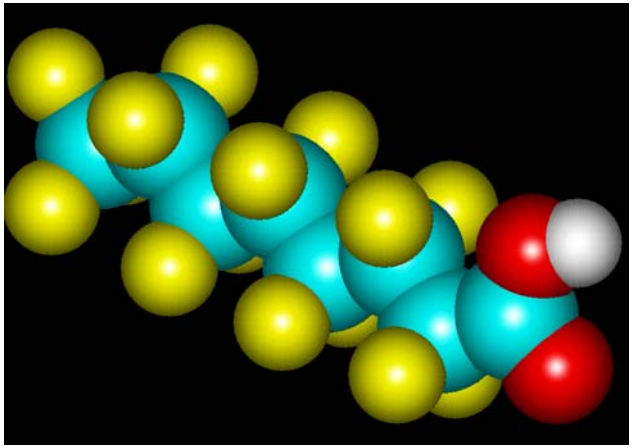
CAS No.	Substance name
26655-00-5	Propane, 1,1,1,2,2,3,3-heptafluoro-3-[(trifluoroethenyl)oxy]-, polymer with tetrafluoroethene
65545-80-4	Poly(oxy-1,2-ethanediyl), α-hydro-ω-hydroxy-, ether with α-fluoro-ω-(2-hydroxyethyl) poly(difluoromethylene) (1:1)
143372-54-7	**Siloxanes and silicones**, (3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl)oxy Me, hydroxy Me, Me octyl, ethers with polyethylene glycol mono-Me ether
24448-09-7	1-Octanesulfonamide, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-N-(2-hydroxyethyl)-N-methyl- (MeFOSE)
68412-68-0	**Phosphonic** acid, perfluoro-C6-12-alkyl derivatives
68412-69-1	**Phosphinic** acid, bis(perfluoro-C6-12-alkyl) derivatives
56773-42-3	Ethanaminium, *N,N,N*-triethyl-, salt with 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluoro-1-octanesulfonic acid (1:1)
69991-67-9	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymerized
119973-85-2	2-Propenoic acid, 2-methyl-, 3-chloro-2-hydroxypropyl ester, polymer with 3,3,4,4, 5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-heneicosafluorododecyl 2-propenoate,
65530-70-3	Poly(difluoromethylene), α, α'-[**phosphini**cobis(oxy-2,1-ethanediyl)]bis[ω-fluoro-, ammonium salt
65530-72-5	Poly(difluoromethylene), α-fluoro-ω-[2-(**phosphono**oxy)ethyl]-, diammonium salt

PFOA – another important PFAS



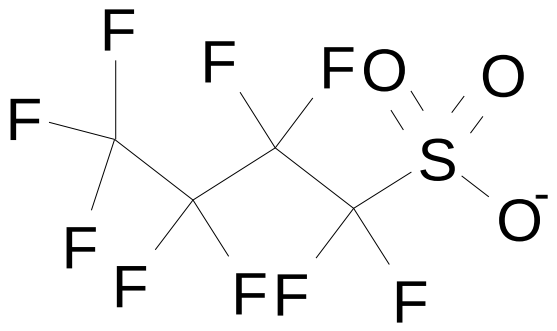
PFOA: Perfluorooctanoic acid

$C_8HF_{15}O_2$



Both PFOS and PFOA are very stable, non-volatile solids.

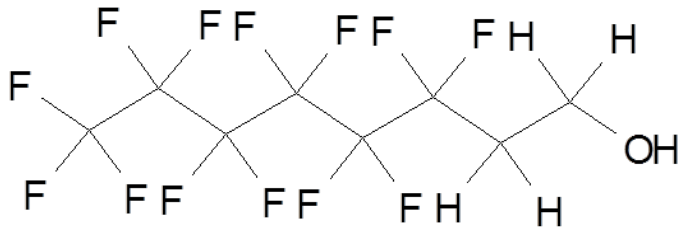
Most used alternatives are other PFAS



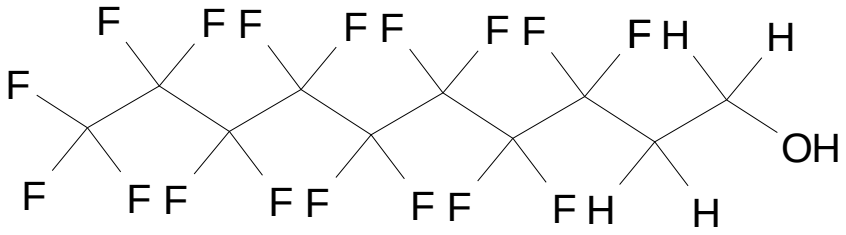
Perfluorobutane sulfonate PFBS

Most used alternatives are other PFCs

Fluorotelomers

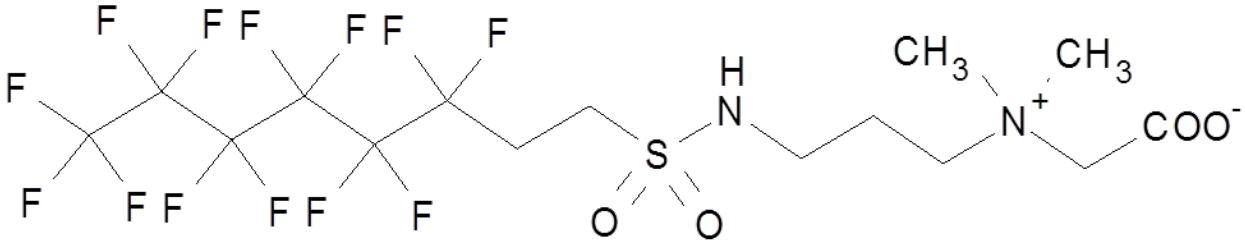


6:2-FTOH



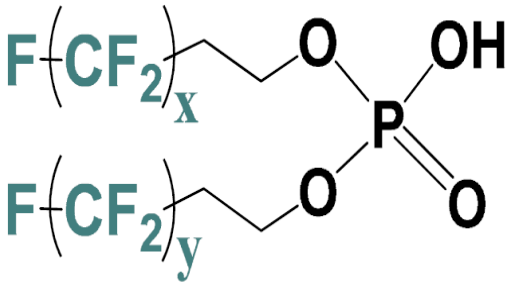
8:2-FTOH

1*H*,1*H*,2*H*,2*H*-Perfluorodecanol

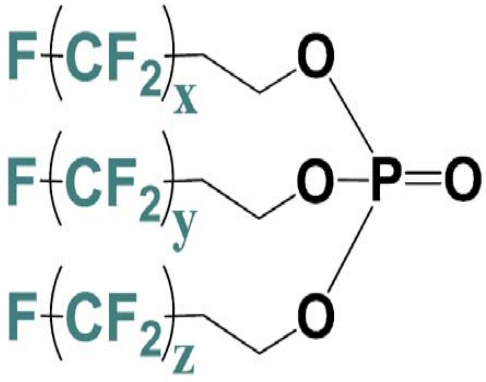


1*H*, 1*H*, 2*H*, 2*H*-perfluorooctane sulfonamidopropyl carboxybetaine

Polyfluorinated surfactants in food packaging of paper and board

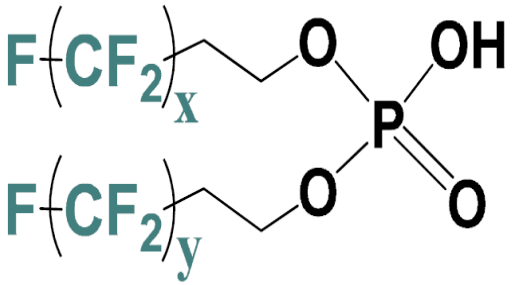


diPAPs

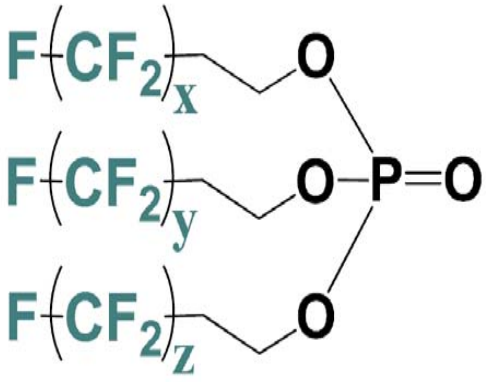


triPAPs

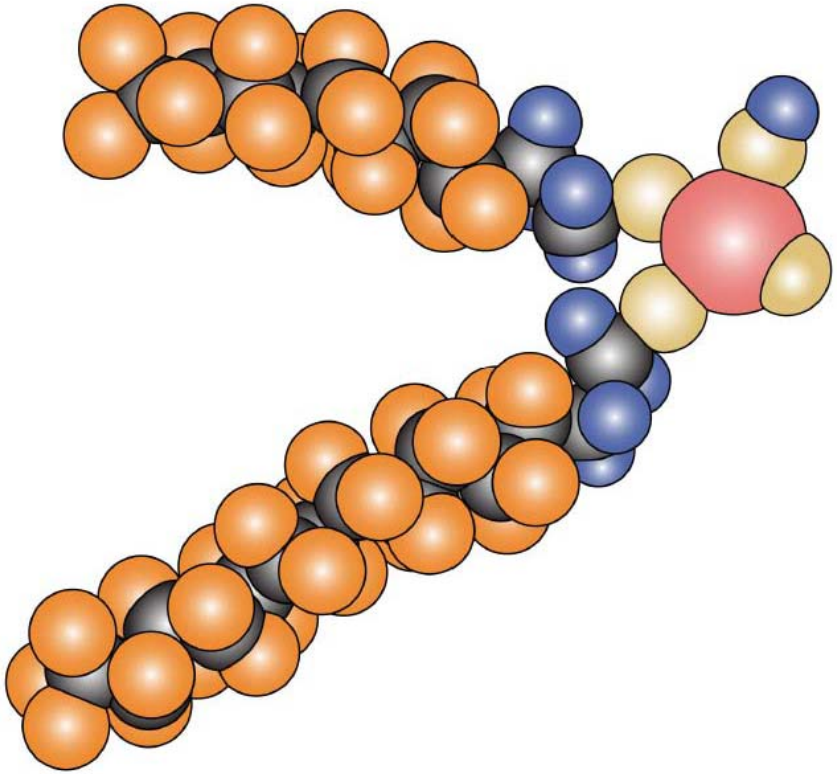
Polyfluorinated surfactants in food packaging of paper and board



diPAPs



triPAPs



Polyfluorinated surfactants in food packaging of paper and board

Comparison of extraction and migration data of Σ(diPAPs) from food packaging

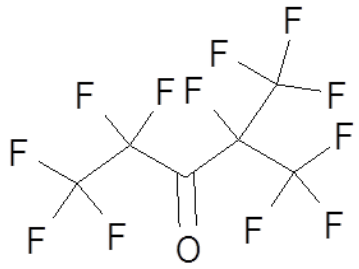
No.	Product	Material	Food kg	Area dm^2	n	Extraction $\mu g \cdot dm^{-2}$	Extraction $\mu g \cdot kg^{-1}$	n	Migration $\mu g \cdot dm^{-2}$	Migration $\mu g \cdot kg^{-1}$	Ratio of migration/ extraction
1-M	Popcorn, Popz, Føtex	Paper	0.100	10.5	6	3420 ± 700	360000 ± 71000	6	10800 ± 11000	1140000± 1160000	3.16
2-M	Organic ryebread mix, Finax	Paper	1.000	6.89	3	3660 ± 3400	25200 ± 2400	3*	8100 ± 11000	55900± 79000	2.21
3-M	Müsli, Finax	Paper	0.750	6.6	3	4070± 160	35800 ± 1400	2	166 ± 29	1460 ± 250	0.041
4-M	Organic falafel, Nutana	Cardboard	0.285	6.58	3	113 ± 46	2600 ± 1100	1	70.9	1460	0.63

Average concentrations ($\mu g\ L^{-1}$) have been corrected for method blanks.

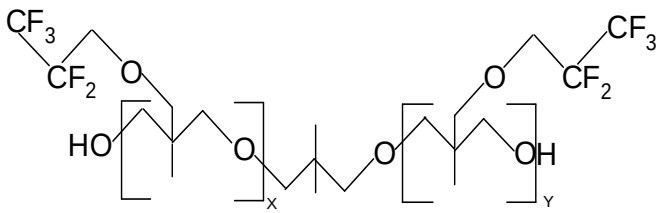
* Extreme variation: The three samples concentrations ($\mu g\ L^{-1}$) were: 910, 463557, <LOD

Xenia Trier, DTU-Food
PhD Thesis 2011

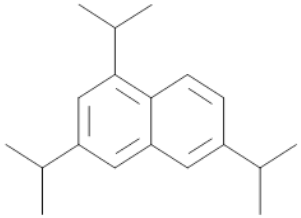
Other alternatives



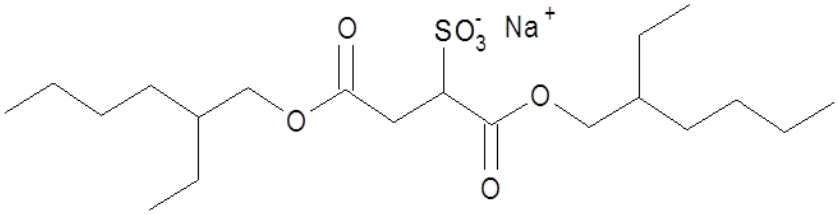
Dodecafluoro-2-methylpentan-3-one



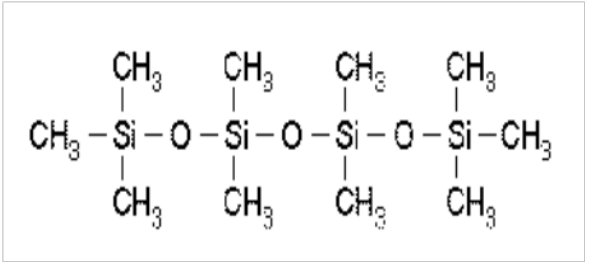
PolyFox



Ruetasolv TTPN



Sulfosuccinate

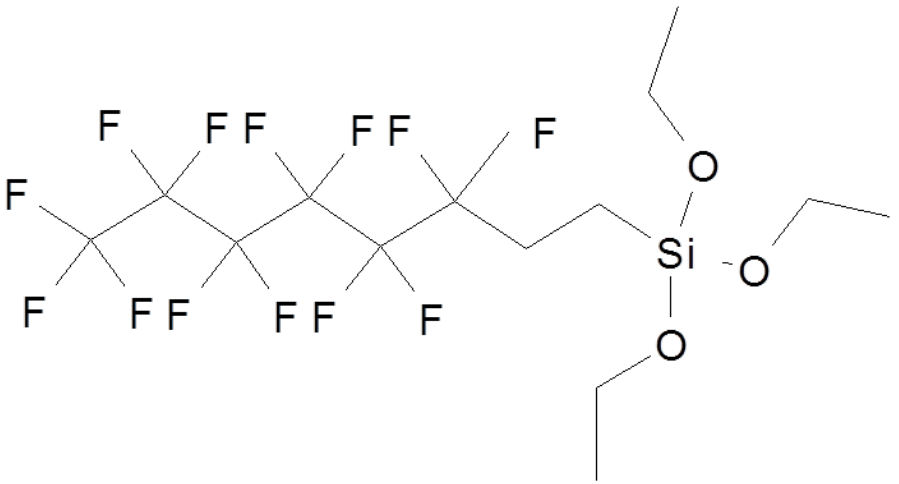


Hexamethyldisiloxane

Mixed PFC - siloxanes

A spray product by “Nanocover” for shinny bathroom floors has recently been banned in Denmark because of lung damage appeared in experimental animals exposed to the product by inhalation.

The agents causing the effect were polyfluorooctylated siloxanes. The formula for one member of a whole family of substances is shown:



Polyfluorooctyl triethoxysilane

Ecotoxicity

Increasing number of studies of ecotoxicology of PFAS, e. g.

Life-time exposure to PFOS adversely affected the life-cycle (egg development, hatching, larval development, survival, metmorphosis and body mass) of the damsefly *Enallagma cyathigerum* (Bots J et al. Environ Pollut 2010;158:901-905)

Human exposures – from where?

- Foods made of blood, liver and kidney? Fish?
- Some release from food packaging, - popcorn snacks!
- Contaminated drinking water
- The widespread application for impregnation of consumer goods, such as clothes, foot wear and carpets could be the most important human exposure. Spray cans!
- Significant amounts of PFOS (up to 2500 ng/g) are found in dust collected by vacuum cleaners in private homes and offices.
- The indoor air concentration of PFOS derivatives are measured to around 3 ng/m^3 - or 25-100 times concentrations outdoors.
- Work environment?

An example for PFOA / PFOS intake estimation

Environ Sci Technol. 2011 Oct 1;45(19):8137-43. Epub 2010 Oct 12.

Determinants of Plasma PFOA and PFOS Levels Among 652 Danish Men.

Eriksen KT, Sørensen M, McLaughlin JK, Tjønneland A, Overvad K, Raaschou-Nielsen O.

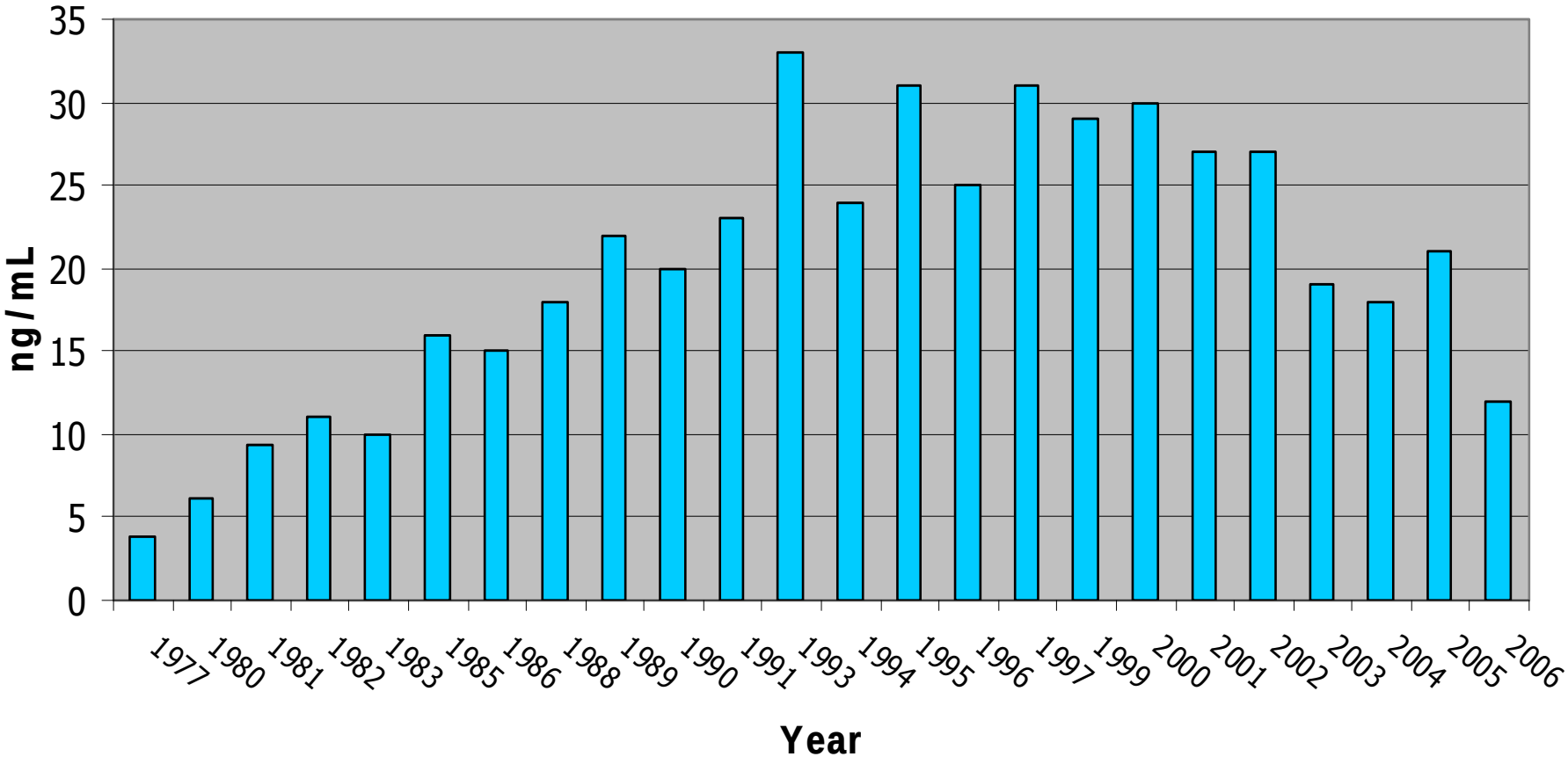
Institute of Cancer Epidemiology, Danish Cancer Society , Copenhagen, Denmark.

Abstract

The sources for human exposure are not well described, but dietary intake is suggested as an important source. In this study of 652 Danish men from the Diet, Cancer and Health cohort, we examined intake of 10 major dietary groups, tap water drinks, alcohol consumption, cooking method, geographical area, age, smoking status, and BMI as potential determinants of PFOA and PFOS plasma levels. Living in the Aarhus area was associated with higher PFOA and PFOS plasma levels compared with living in the Copenhagen area, and never smokers had higher levels than current smokers. Frying as compared with other cooking methods was a determinant of PFOA and PFOS levels. BMI and alcohol consumption were inversely associated with both compounds. Among the dietary groups, only intake of eggs was significantly positively associated with PFOS plasma levels. In future studies, PFOA and PFOS levels in air, dust and water samples should be measured to elucidate further the sources of exposure; exposure through diet needs to be studied in greater detail. Our finding of a higher body burden of PFOA and PFOS among never smokers also warrants further evaluation.

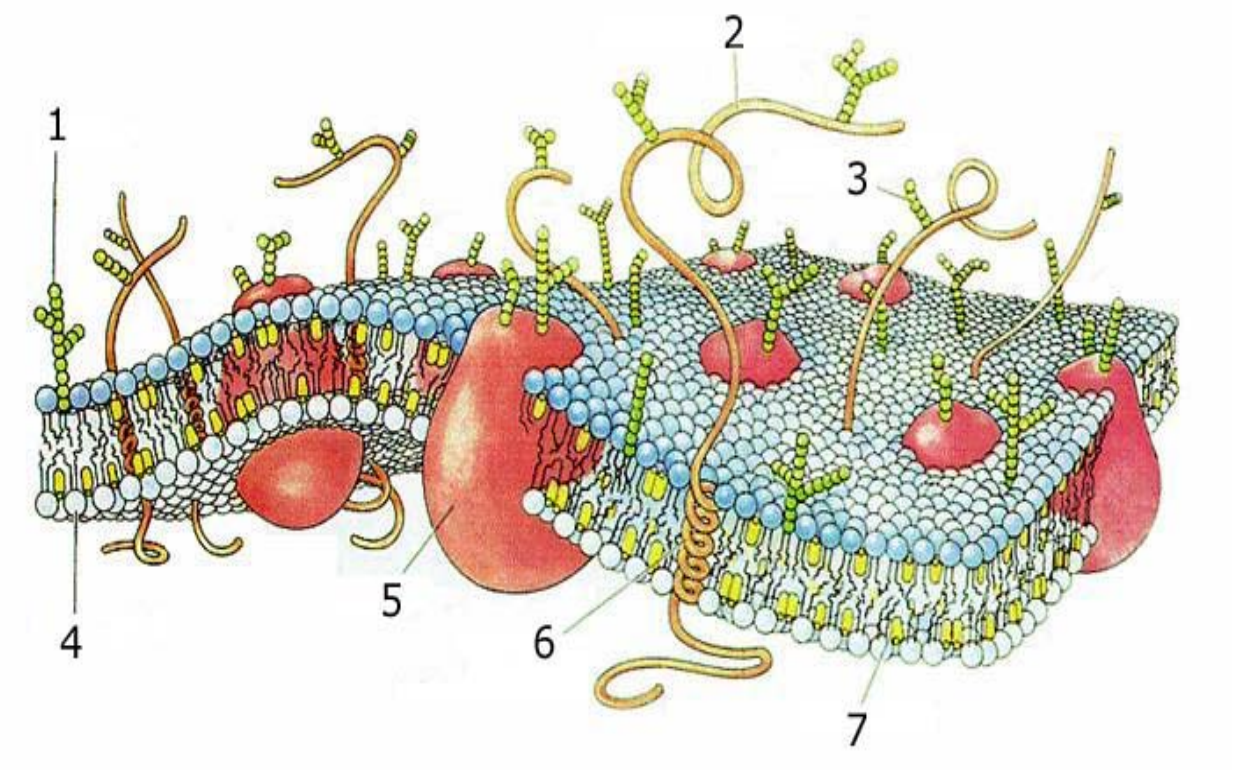
Trend of PFOS in blood in Norwegians

(Haug et al. 2010)



PFAS has many adverse effects!

- are readily absorbed and binds to proteins in blood,
- binds to proteins in cell membranes and change the membrane properties (fluidity):



PFAS has many adverse effects!

- Accumulate mainly in organs such as liver, kidney and spleen but also in testicles and brain,

- Half-lives *in blood* from retired fluorochemical workers:
  - 5.8 years for PFOS
  - 8.5 years for PFHxS (perfluorohexane sulfonate) and
  - 3.8 years for PFOA

- The half-lives are probably longer for the less exposed general population. For PFOA half-lives of 2.9 and 8.5 years for respectively high and low exposure from drinking water (Seals et al. EHP 2011;119:119-124).

- Since the excretion of these chemicals in humans is very limited they are redistributed to various internal organs.

- In comparison, the blood half-lives in experimental animals are hours or days because of a significant excretion.

PFAS has many adverse effects!

- The acute toxicities of PFAS is moderate. The toxicity of related substances *increases* with chain length.
- The liver is the primary *target organ*, and peroxisome proliferation is induced in rat liver, as well as induction of various enzymes involved in metabolisms of fats.
- Association between PFAS and cholesterol levels in blood (Frisbee et al. 2010)
- PFOS alters immune response in mice at low exposure levels. PFOS concentration in blood serum was 92 ng/g or only 3 times higher than average concentration in humans (Peden-Adams et al. Toxicol Sci 2008; 104: 144-154).
- PFOS and PFOA affect human immune cells mainly with regards to natural killer-cell cytotoxicity and the pro-inflammatory cytokine release by stimulated macrophages (Brieger et al. 2011).

PFAS has many adverse effects!

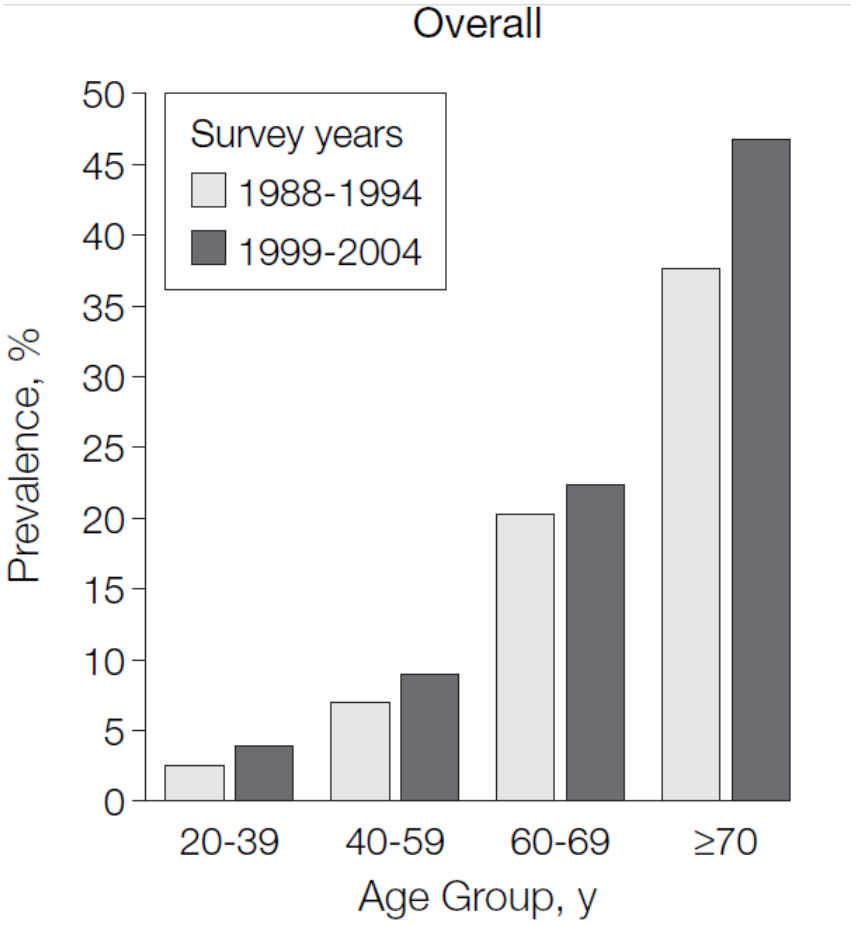
Endocrine disruption

- PFOS affect the blood levels of various hormones. In rats levels of testosterone are decreased, and levels of estradiol are increased.
- In female rats PFOS exposure did affect the neuroendocrine system in rats (Austin et al. 2003).
- Higher concentrations of serum PFOA and PFOS are associated with current thyroid disease in the U.S. general adult population (Melzer et al. Environ Health Perspect 2010;118:686–692), but other studies has not confirmed that.

Chronic kidney disease

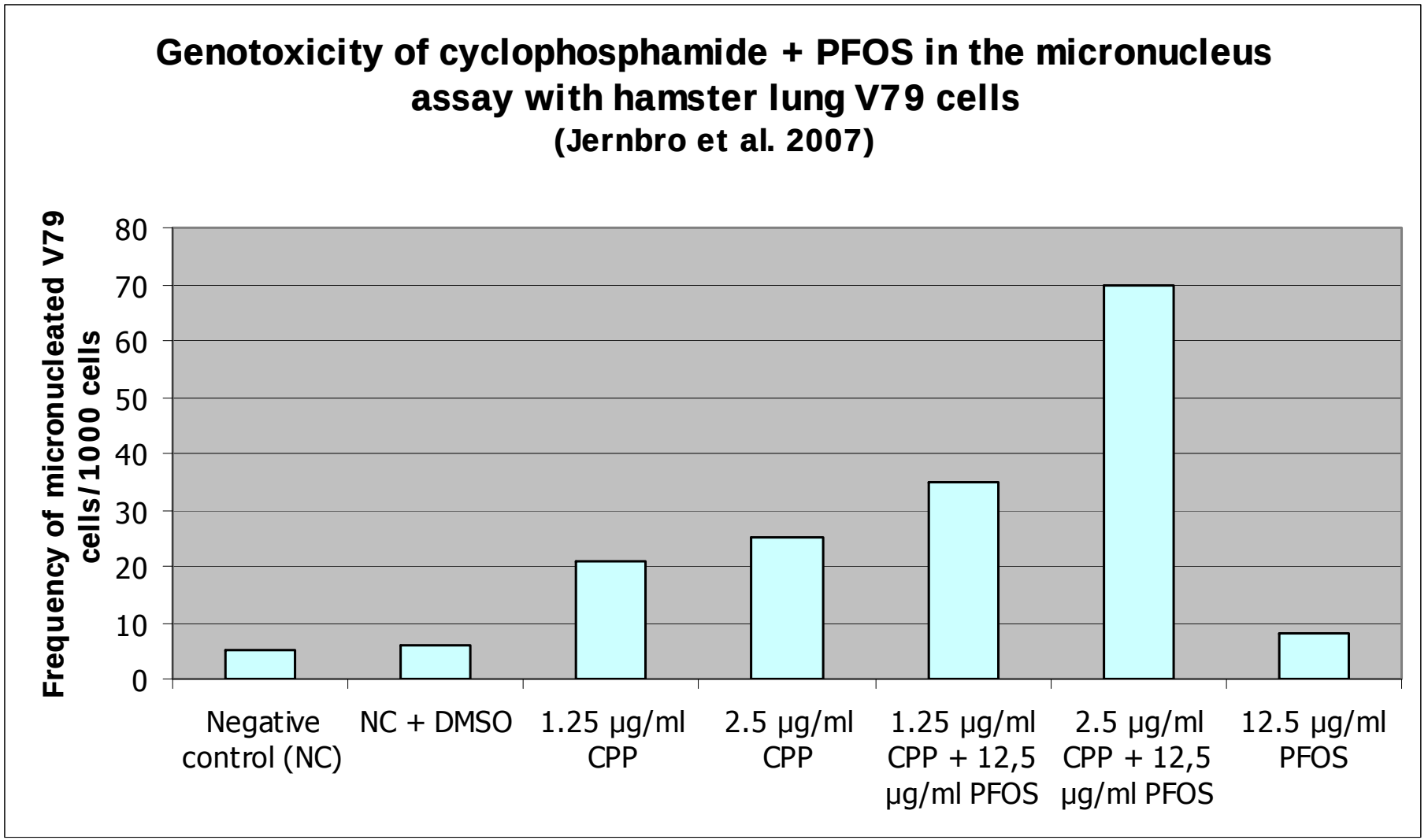
Data from the NHANES study was used to show an positiv association between serum levels of PFAS and chronic kidney disease defined as a glumural filtration rate of less than 60 ml/minute/1.73 m^2 (Shankar et al. Am J Epidemiol 2011; 174: 893-900).

This disease has increased during the later years (Coresh et al. JAMA 2007; 298:2038-2047).



Prevalence of Chronic Kidney Disease (CKD) Stages by Age Group in NHANES 1988-1994 and 1999-2004

PFOS increases the genotoxicity of cyclophosphamide



Cancer

PFOS and EtFOSE have caused liver cancer in rodents.

One study from the work environment reports an increased incidence of urinary bladder cancer in workers with high exposure to perfluorooctane sulfonyl fluoride (PFOSF).

An animal bioassay with more generations of mice exposed to low doses of PFOA in drinking water, a delay in mammary gland development and/or lactational differentation in female ofsprings were observed across three generations (White et al. EHP 2011;119:1070-1076).

A new study of Inuits from Greenland showed a significant association between serum PFAS levels and the risk of breast cancer (Bonefeld-Jorgensen et al. Environmental Health 2011; 10:88)

Attention and behavior problems in children

In the large National Health and Nutrition Examination Survey (NHANES) 1999-2004:

- 48 of 571 children aged 12-15 included in that survey had the diagnosis of attention deficit hyperactivity disorder (ADHD).
- Increased odds of ADHD were significantly associated with higher levels of PFOS, PFOA and PFHxS.
- Reference: Hoffman K et al. Exposure to polyfluoroalkyl chemicals and attention deficit hyperactivity disoreder in U.S. children aged 12-15 years. Environmental Health Perspectives 2010;118(12):1762-1767.

Two additional studies from 2011:

- Gump, BB, Q Wu, AK Dumas and K Kannan. 2011. Perfluorochemical (PFC) exposure in children: Associations with impaired response inhibition. Environmental Science and Technology 2011, 45, 8151–8159.
- Stein, CR, and DA Savits. 2011. Serum perfluorinated compound concentration and attention deficit/hyperactivity disorder in children aged 5 to 18 years. Environ Health Perspect 2011; 119:1466–1471

Effects on the unborn child and reproduction

Apelberg et al. 2007

- Prenatal exposure to PFOS/PFOA linked to lower birth weight

Fei et al. 2008

- Maternal PFOA was associated with shorter infant length at birth

Washino et al. 2009

- Maternal PFOS serum levels negatively correlated with birth weight

Fei et al. 2009

- Higher maternal levels of PFOS and PFOA were associated with delayed pregnancy

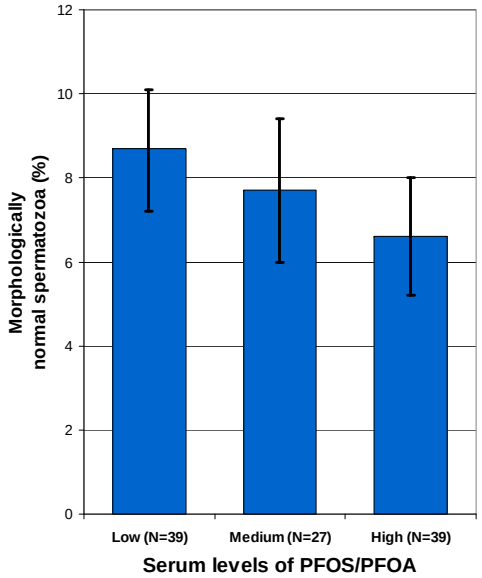
Fei et al. Scand J Work Environ Health 2010; 36(5): 413–421.

- Maternal concentrations of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) and shorter duration of breastfeeding.

Effect on testicular function/semen quality

A Danish pilot study detected a statistical significant difference in percentage of morphologically normal sperms between low and high group of PFOS + PFOA concentration in blood.

Blood serum levels in young Danish men	Total (N=105)	
	Median	Range
PFOS conc. ng/ml	24.5	10.6-53.1
PFOA conc. ng/ml	4.9	1.9-8.6



Joensen et al. EHP 2009

Conclusions

- PFAS's are persistent, bioaccumulative and toxic - dependent on their chain length
- PFOS and derivatives are the most hazardous PFAS and most wide-spread in the global environment
- Many PFAS's are transported to and found in the most remote places on Earth, including the Arctic and the highest levels are found in the Polar Bear liver
- Every human being in the World do have perfluororchemicals in their blood and organs and more and more health effects are discovered
- PFOS was the first PFAS to be regulated but with many accepted uses and exemptions
- There are alternatives to all PFOS uses, but the alternatives may not always be perfect
- Presently, these alternatives will mostly be other PFAS's but with shorter chain lengths
- Non-fluorinated alternatives exit for some applications but not always with the same quality of performance.

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Thank You!

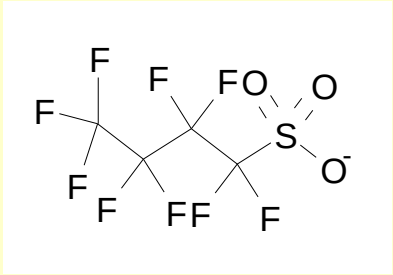
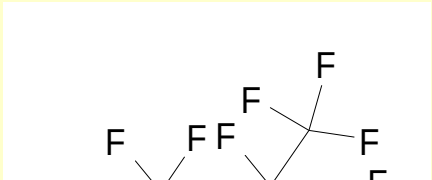
Use area	Use of PFOS-related substances	Used alternatives
Impregnation of textiles, leather and carpets	PFOS-related substances have been phased out in most OECD countries.	Other fluorinated compounds, like C_6-fluorotelomers and PFBS, silicone based products, stearamidomethyl pyridine chloride
Impregnation of paper and cardboard	PFOS-related substances have been phased out in most OECD countries.	Fluorotelomer-based substances/phosphates, mechanical processes.
Cleaning agents, waxes/polishes for cars and floors	PFOS-related substances have been phased out in most OECD countries.	Fluorotelomer-based substances, fluorinated polyethers, C_4-perfluorinated compounds.
Surface coating, paint and varnish	PFOS-related substances have been phased out in most OECD countries.	Telomer-based compounds, fluorinated polyethers, PFBS, isopropylated aromatics, aliphatic fatty alcohols, silicone surfactants, sulfosuccinates.
Photographic industry	A shift to digital techniques has reduced the use drastically.	Telomer-based surfactants products, hydrocarbon

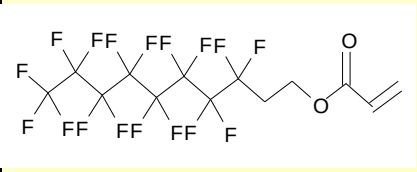
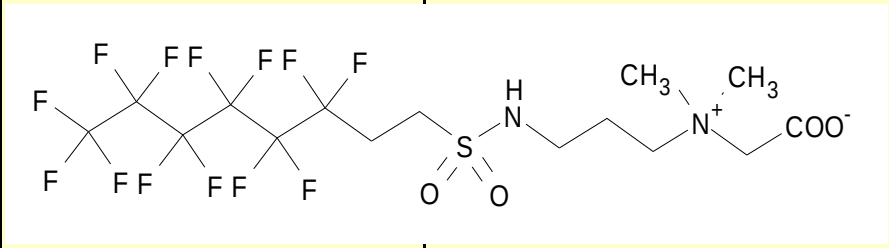
Use area	Use of PFOS-related substances	Used alternatives
Electric and electronic parts	PFOS based chemicals are or have been used in the fabrication of digital cameras, cell phones, printers, scanners, satellite communications, and radar systems etc.	For most of these uses, alternatives are available or are under development.
Semiconductor industry	PFOS still used but in lower concentrations	No substitutes with same fitness for use identified. May take up to 5 years. May be PFBS, fluorinated polyethers or telomers?
Aviation hydraulic oils	PFOS-related compounds may still be used.	Other fluorinated substances and phosphate compounds could be used.
Pesticides	Sulfluramid used in some countries as active substance and surfactant in pesticide products for termites, cockroaches and other insects. Other fluorosurfactants may be	Synthetic piperonyl compounds, S-Methoprene, Pyriproxyfen, Fipronil, and Chlorpyrifos are alternative active substances, eventually in combination. Alternative surfactants may be

Use area	Use of PFOS-related substances	Used alternatives
Medical devices	Old video endoscopes at hospitals contain a CCD colour filter that contains a small amount of PFOS. PFOS is also used as an effective dispersant, for contrast agents in radio-opaque catheters.	Repairing such video endoscopes requires a CCD colour filter containing PFOS. New CCD filters are PFOS-free. For radio-opaque ETFE perfluorobutane sulfonate (PFBS) can substitute PFOS.
Metal plating	PFOS-compounds are still used in hard chrome plating. Cr-III has replaced Cr-VI in decorative chrome plating.	Some non-fluorinated alternatives marketed but not considered the same fitness for use in hard chrome plating. May change. Physical barriers? A C_6-fluortelomer may be efficient?
Fire-fighting foams	PFOS-related substances have been phased out in most OECD countries in new products. Stocks are used.	Fluorotelomers based on C_6-perfluoro, fluorine-free alternatives for training exercises and other places than offshore.
Oil production and mining	PFOS derivatives may occasionally be used as surfactants in the oil and	Telomer-based fluorosurfactants, perfluoroalkyl-substituted amines, acids, amino acids and

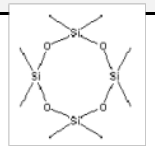
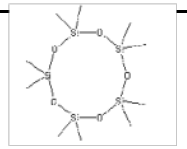
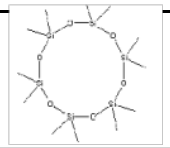
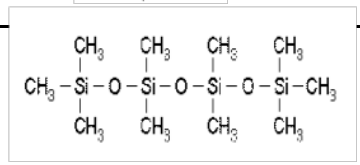
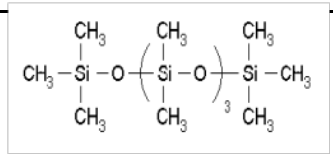
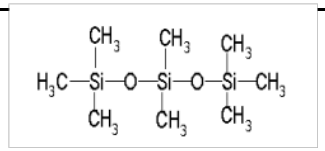
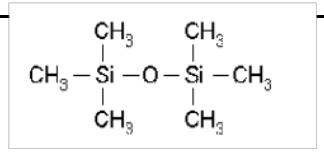
Alternative compound	Product trade name	Company	Used in / used for
Perfluorobutane sulfonate (PFBS) or based on different C4-perfluorinated compounds	Novec ™ Scotchgard™	3M	Paint and coatings industry, electronic coating; industrial and commercial cleaning; stain protectors for carpets, leather, furniture, automotives, hard surfaces and other apparels
Perfluorobutyl methyl ethers	Novec™	3M	Industrial cleaning
Dodecafluoro-2-methylpentane-3-one	Novec™ 1230	3M	Fire-fighting foam
Potassium perfluoroethyl cyclohexyl sulfonate	FC-98	3M	Hydraulic fluids
Fluorotelomer alcohols and esters	Zonyl® Capstone™	DuPont™	Surfactant, coating, printing, textile and chemical industries, chrome plating
C_6-fluorotelomer sulfonamide	Forafac™ 1157, 1183	DuPont™	Fire-fighting foam

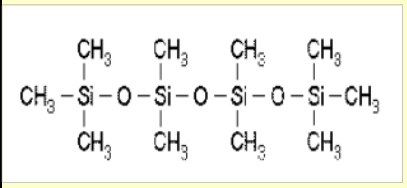
Alternative compound	Product trade name	Company	Used in / used for
CF_3 or C_2F_5 fluoroalkyl polyethers	PolyFox™	OMNOVA Solutions Inc.	Surfactant and flow-, level-, and wetting additive for coating formulations and floor polish.
Propylated naphthalenes or biphenyls	Ruetasolv™	Rütgers Kureha Solvents	Water repelling agents for rust protection systems, marine paints, coatings, etc.
Fatty alcohol polyglycol ether sulfate	Emulphor™	BASF	Levelling and wetting agents
Sulfosuccinate	Lutensit™	BASF	Levelling and wetting agents
	Edaplan™ LA 451	Münzing Chemie	Paint and coating industry: Wetting and dispersing agents for water-based applications e.g. wood primers
	Hydropalat™ 875	Cognis	
Siloxanes and silicone polymers	WorléeAdd™	Worlée-Chemie	Wetting agents in the paint and ink industry
	Advantex™	Bluestar Silicones	Impregnation of all-weather textiles. Also related

Alternative compound	General info	Health effects	Environmental effects
Perfluorobutane sulfonate (PFBS) or based on different C_4-perfluorocompounds 	There is no information available about the specific chemicals in use, only information about PFBS and its potassium salt (PFBSK) from unpublished laboratory test reports.	rat oral and skin LD50 were >2 g/kg bw; irritating to eyes; oral rat NOAEL values of 100-300 mg/kg bw/day	Persistent in the environment and detected in increasing concentrations in some water bodies; bioaccumulation in wildlife and humans seems to be much less than for PFOS; strongly acidic, highly water soluble with a low vapour pressure and poorly adsorbed to soils and sediments; expected to remain in the water compartment on release into the environment
Dodecafluoro-2-methylpentane-3-one	Fire protection fluid	There is a lack of public peer-reviewed data.	There is a lack of public peer-reviewed data.
Methyl nonafluorobutyl ether	Industrial cleaning		
Potassium	Hydraulic liquids		

Alternative compound	General info	Health effects	Environmental effects
Fluorotelomer alcohols and esters 	C_8-fluorotelomers to be phased out; degrades to perfluorocarboxylic acids/salts (PFCAs) such as perfluorooctanoate (PFOA)	Lack of health data for chemicals used in practice; a few data exists on adverse effects in experimental animals and laboratory tests; more info about final degradation products. The toxicity of the degradation products increases with fluoro chain length. PFOA has been shown to be tumorigenic and immunotoxic in laboratory animals	Lack of environmental data on the many specific and complex chemicals used in practice. Some are volatile and may undergo long-range air transportation. Degrades to PFCAs perfluorinated acids widely detected in the environment and wildlife. The environmental hazard, including bioaccumulation, increases with chain length, but all perfluorinated alkyl chains are completely persistent in nature.
C_6 fluorotelomer sulfonamide compounds 	Fire-fighting		
Fluorinated co-polymers.	Used for finishing and protection of textiles, leathers and	Lack of specific health data on the active fluorinated	Lack of data. Probably only the solvent and degradation products of

Siloxanes

Abbreviation	Name	CAS no.	Structure
D4	Octamethyl-cyclotetrasiloxane	556-67-2	
D5	Decamethyl-cyclopentasiloxane	541-02-6	
D6	Dodecamethyl-cyclohexasiloxane	540-97-6	
MM(HMDS)	Hexamethyldisiloxane	107-46-0	
MDM	Octamethyltrisiloxane	107-51-7	
MD2M	Decamethyltetrasiloxane	141-62-8	
MD3M	Dodecamethylpenta-siloxane	141-63-9	

Alternative compound	General info	Health effects	Environmental effects
Siloxanes and silicone polymers 	Siloxanes are building blocks for silicone products and contain units with the general formula R_2SiO, where "R" represents hydrogen or a hydrocarbon group. They may be straight chain or cyclic compounds and vary in weight from a few hundred to several hundred thousand g/mol for the polymers.	The overall knowledge on siloxane toxicity is very limited. The linear siloxane hexamethyl disiloxane appeared to have lower potential for liver toxicity, but higher potential for lung toxicity, than the cyclic substances. Decreasing toxicity with increasing chain length; may cause skin irritation	Siloxanes are very stable and persistent compounds without degradation in the environment. The cyclic- and short-chained linear siloxanes are bioconcentrated in aquatic organisms and toxic to aquatic organisms; R51/53 D5 is measured in environmental air in Sweden (<10 ng/m^3). Degraded by OH radicals.