Available online at www.sciencedirect.com
ScienceDirect
Int. J. Hyg. Environ. Health 212 (2009) 499–504
International Journal of Hygiene and Environmental Health
www.elsevier.de/ijheh

One-year follow-up of perfluorinated compounds in plasma of German residents from Arnsberg formerly exposed to PFOA-contaminated drinking water

Jürgen Hölzer[a,*], Thomas Göen[b], Knut Rauchfuss[c], Martin Kraft[d], Jürgen Angerer[b], Peter Kleeschulte[e], Michael Wilhelm[a]

[a]*Department of Hygiene, Social and Environmental Medicine, Ruhr-University Bochum, 44801 Bochum, Germany*
[b]*Institute and Outpatient Clinic of Occupational, Social and Environmental Medicine, University Erlangen-Nuremberg, Germany*
[c]*North Rhine-Westphalia State Agency for Nature, Environment and Consumer Protection, Recklinghausen, Germany*
[d]*Ministry of Environment and Conservation, Agriculture and Consumer Protection, North Rhine-Westphalia, Düsseldorf, Germany*
[e]*Public Health Department of the Hochsauerlandkreis, Meschede, Germany*

Received 3 March 2009; received in revised form 3 April 2009; accepted 13 April 2009

Abstract

In Arnsberg, Sauerland area Germany, 40 000 residents were exposed to PFOA-contaminated drinking water (500-640 ng PFOA/l; May 2006). In July 2006, the PFOA-concentrations in drinking water were lowered significantly by activated charcoal filtering in the waterworks, mostly below the limit of detection (10 ng/l). A first human biomonitoring study performed in autumn 2006 revealed that PFOA-concentrations in blood plasma of residents living in Arnsberg were 4.5–8.3 times higher than in the reference groups. One year after the first survey, all participants (2006: 164 mothers, 90 children, 101 men) were invited to take part in a follow-up study. It was the aim of the study to determine the decline of the PFOA-concentrations in blood plasma. 288 persons (81%) were included in the statistical analysis. The (geometric) mean PFOA-concentrations in blood plasma of Arnsberg's residents decreased from 22.1 to 17.4 μg/l in children, from 23.4 to 18.8 μg/l in mothers and from 25.3 to 23.4 μg/l in men within one year. The average (geometric mean) changes in each individual's PFOA-concentrations were approximately 10 (men), 17 (mothers) and 20 (children) percent/year. The observed decline in PFOA-concentrations indicates a slow elimination in humans. This finding in groups of the general population is in agreement with data on long elimination half-lives observed in occupationally exposed workers.

Keywords: Perfluorinated compounds; PFC; PFOA; PFOS; Human biomonitoring; Follow-up; Children; Adults; PFC study Sauerland; Elimination rate

Introduction

Perfluorooctanoate (PFOA) and perfluorooctanesulfonate (PFOS) are persistent in the environment and have been detected globally in blood and tissues from animals and humans. The highest PFOS- and

*Corresponding author. Tel.: +49 234 322 26994; fax: +49 234 32 06994.
E-mail address: juergen.hoelzer@rub.de (J. Hölzer).

1438-4639/$ - see front matter © 2009 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijheh.2009.04.003

PFOA-concentrations in human blood samples were measured in workers employed in fluorine production plants (OECD, 2002; Olsen et al., 2003). The exposure of the general population seems to differ among countries. Fromme et al. (2009) recently summarized human biomonitoring data and reported that mean concentrations for some perfluorinated compounds (PFCs) from North American populations appear to be slightly higher than from European, Asian, and Australian populations studied. Significant reductions in PFOS (32%) and PFOA (25%)-concentrations in blood serum samples were reported from a comparison of the representative National Health and Nutrition Examination Surveys 2003–2004 and 1999–2000 (Calafat et al., 2007).

There are few reports on increased PFOA-exposure of general population groups, which mainly occurred via ingestion of contaminated drinking water (Little Hocking, Ohio, USA: Emmett et al., 2006a, 2006b; Pausten-bach et al., 2007; Minnesota, USA: ATSDR, 2008; Arnsberg, Sauerland area, Germany: Wilhelm et al., 2008). In Arnsberg, Germany, 40 000 residents had been exposed to PFOA-contaminated drinking water (500-640 ng PFOA/l; May 2006). Recently, we reported on the results of a cross-sectional study in Arnsberg to assess the internal exposure of Arnsberg's residents to PFOA (Hölzer et al., 2008). PFOA concentrations in blood plasma of residents living in Arnsberg were 4.5–8.3 times higher than in the reference groups (arithmetic means Arnsberg/controls: children 24.6/5.2 μg/l, mothers 26.7/3.2 μg/l, men 28.5/6.4 μg/l). In July 2006, waterworks installed activated charcoal filtering to remove PFOA from drinking water. One year after the first survey, all participants were invited to take part in a follow-up human biomonitoring study. It was the aim of the study to determine and to quantify a suspected change of the PFOA-concentrations in blood plasma. Additionally, PFOS, perfluorohexanoate (PFHxA), perfluorohexanesulfonate (PFHxS), perfluor-opentanoate (PFPA) and perfluorobutanesulfonate (PFBS) were measured.

Materials and methods

The survey was designed as a follow-up study. Invitation letters were sent to all residents of Arnsberg, who participated in the first study one year ago (2006: 164 mothers, 90 children, 101 men). 291 persons (82%) took part. In 2006, children were 5-6 years old.

Identical standard materials for venipuncture and blood sampling (anticoagulant K-EDTA) were used in the first cross-sectional study as well as in the follow-up study. Analytical methods also remained unchanged. Human plasma samples were analyzed for PFOS, PFHxS, PFBS, PFOA, PFHxA, and PFPA by solid phase extraction, high performance liquid chromatography (HPLC) and detection by a tandem mass spectrometer. Limits of detection (LOD) were 0.1 μg/l for PFOS, PFHxS, PFBS and PFOA, and 1.0 μg/l for PFHxA and PFPA, based on a 3-fold signal to noise-ratio. The coefficients of variation (CVs) were 6.7% at 9.6 μg/l (PFOS) and 7.2% at 5.4 μg/l (PFOA).

Details on the PFC-analysis in blood plasma, the sampling strategy and response data of the first cross-sectional study and the location of the study areas have been reported by Hölzer et al. (2008).

All study participants filled in a short questionnaire for self-completion (for estimation of height, weight, smoking, alcohol consumption, diseases, medication). A second questionnaire was administered by interview on the day of the examination mainly to assess changes in drinking water consumption and diet over the last 12 months.

Written informed consent was obtained from the participants and the parents of the children before the study. The study was approved by the ethical commission of the Ruhr-University of Bochum and was conducted in accordance with the ethical principles for medical research involving human subjects as defined by the Helsinki Declaration.

For PFC-concentrations below the LOD, an imputed value equal to 1/2 the LOD was used. Minima, lower quartiles, medians, upper quartiles, maxima and geometric means (with 95% confidence intervals) of the PFCs in plasma are presented. Student's *t*-Test for paired samples was used to evaluate the differences between $\log_{10}$(PFOA, PFOS and PFHxS)-concentrations in 2006 and 2007. All data were analyzed using the statistical software package SAS v. 9.1.3 (SAS Institute Inc., Cary, NC, USA).

Results

291 participants (82%) of the first human biomonitoring study in Arnsberg 2006 took part in the follow-up study (Table 1). Analysis was limited to 288 individuals (81 percent), whose blood sampling dates were less than 13 months apart. The time periods between two sampling dates ranged from 335 to 386 (Median 359, $N = 288$) days.

In July 2006, waterworks installed activated charcoal filtering and reactivated the filters in regular intervals. Subsequently, the PFOA-concentrations in drinking water were lowered significantly, mostly below the limit of detection (LOD: 10 ng/l, Fig. 1).

The individual PFOA-concentrations in 2006 and 2007 are plotted in Fig. 2. Mean PFOA-concentrations in the blood plasma of Arnsberg's residents decreased

Table 1. Response rates of the different subgroups in the follow-up study performed in autumn 2007.

	Men		Mothers		Children		Sum	
	N	%	*N*	%	*N*	%	*N*	%
Written invitation sent to all study participants of the first biomonitoring study 2006	101		164		90		355	
… Unavailable/no contact established	2	2.0	7	4.3	3	3.3	12	3.4
… Refused consent	9	8.9	13	7.9	7	7.8	29	8.2
… Gave consent to participate	90	89.1	144	87.8	80	88.9	314	88.5
… Failed to appear/no blood withdrawal	6	5.9	5	3.0	12	13.3	23	6.5
Blood samples (PFCs measured)	84	83.2	139	84.8	68	75.6	291	82.0

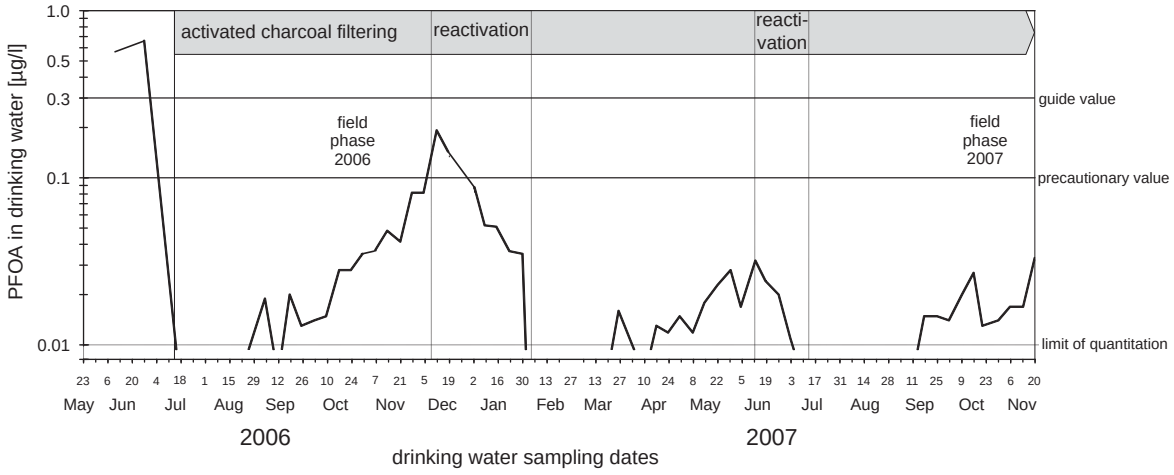

Fig. 1. PFOA-concentrations in drinking water in Arnsberg between May 2006 and April 2008. Weekly analyses were performed by North Rhine–Westphalia State Agency for Nature, Environment and Consumer Protection, Germany. Health based precautionary value (long term minimum quality goal) for non-genotoxic substances; guide value: strictly health based guide value for safe lifelong exposure of all population groups. Definitions according to DWC (2006) for composite PFOA and PFOS concentrations.

from 22.1 to 17.4 µg/l in children, 23.8 to 18.8 µg/l in mothers and 25.7 to 23.4 µg/l in men between the two sampling dates (geometric means, Table 2). These numbers correspond to a decline of 20 (children), 17 (mothers) and 10 (men) percent, in comparison to the concentrations measured in 2006. In 23 individuals (4 children, 4 mothers, 15 men), PFOA-concentrations increased slightly (0.05 to 5.1 µg/l, 0.1 to 15.6%).

In comparison to 2006, also the individual PFOS-concentrations in 2007 decreased by 9% (geometric means, children), 10%(mothers) or 8%(men), PFHxS by about 9% (children) or 11%(mothers, men, Table 3). In 2007, PFBS was detected in 8 of 68 samples of the children (2006: 30 of 90), in 4 of 82 of the men (2006: 13 of 101) and in none of the mothers (2006: 7 of 164, LOD: 0.1 µg/). PFPA and PFHxA were not detected (LOD: 1 µg/l) in any sample neither in 2006 nor in 2007.

Discussion

The PFOA-concentrations (geometric means) decreased significantly between 2006 and 2007 by 20 percent (children), 17 percent (mothers) and 10 percent (men) within one year (335 to 386, median 359 days). The observed decline in PFOA-concentrations indicates a slow elimination in humans. This finding is in agreement with actual literature data referring mainly to occupationally exposed persons.

Only few data on repeated PFC-analyses of humans are published. Ubel et al. (1980) reported a case study of one worker occupationally exposed to fluor chemicals. Organic fluorine concentrations measured in the worker's blood serum one week and 14 months after termination of the exposure were 66 and 44 ppm, respectively, suggesting a slow elimination in humans. Based on a five years follow up study on 26 retired

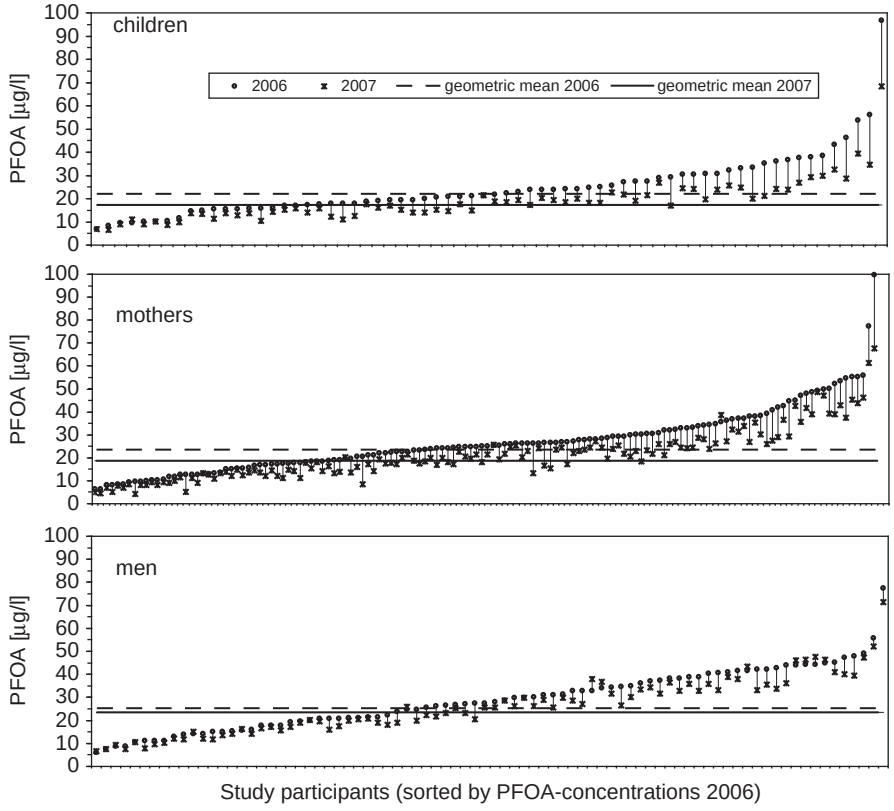

Fig. 2. PFOA-concentrations in blood plasma of 68 children, 138 mothers and 82 men in Arnsberg. Blood sampling dates approximately one year apart (2006 and 2007). Data sorted by increasing PFOA-concentrations 2006.

Table 2. Range and geometric means of the PFOA-, PFOS- and PFHxS-concentrations in blood plasma of all children, mothers and men who took part in both biomonitoring studies 2006 and 2007.

	Children ($N = 68$)		Mothers ($N = 138$)		Men ($N = 82$)	
	2006	2007	2006	2007	2006	2007
PFOA (µg/l)						
Minimum	6.7	6.7	6.4	4.2	6.1	6.5
Maximum	96.6	68.5	99.7	67.5	77.5	71.5
Geometric mean (GM)	22.1	17.4	23.8	18.8	25.7	23.4
Lower limit 95% confidence interval GM	19.7	15.7	21.8	17.2	23.0	20.9
Upper limit 95% confidence interval GM	24.8	19.2	25.9	20.6	28.8	26.1
PFOS (µg/l)						
Minimum	2.4	2.2	2.1	1.7	2.7	3.7
Maximum	20.6	18.8	16.4	15.0	36.2	49.9
Geometric mean (GM)	5.0	4.5	5.8	5.3	10.6	10.2
Lower limit 95% confidence interval GM	4.5	4.1	5.4	4.9	9.5	9.1
Upper limit 95% confidence interval GM	5.6	5.0	6.2	5.7	11.8	11.4
PFHxS (µg/l)						
Minimum	0.5	0.5	<LOD	0.4	0.7	0.7
Maximum	13.4	11.8	5.7	4.2	8.7	6.7
Geometric mean (GM)	1.2	1.1	1.1	1.0	2.5	2.2
Lower limit 95% confidence interval GM	1.0	0.9	1.0	0.95	2.3	2.0
Upper limit 95% confidence interval GM	1.3	1.2	1.2	1.1	2.8	2.4

Blood sampling dates were 335 to 386 (Median 359) days apart. $N = 288$. LOD = limit of detection (0.1 µg/l). All differences between log (PFOA, PFOS and PFHxS)-concentrations in 2006 and 2007 were statistically significant ($P < 0.05$, Student's t-test for paired samples).

Table 3. PFOA, PFOS and PFHxS-concentrations in blood plasma.

Individual changes (positive numbers indicate a reduction, negative numbers indicate an increase)	Children ($N = 68$)		Mothers ($N = 138$)		Men ($N = 82$)	
	Abs.	%	Abs.	%	Abs.	%
PFOA (µg/l)						
Minimum	−1.4	−14	−2.8	−8	−5.1	−16
Maximum	28.2	43	32.1	60	9.2	28
Geometric mean (GM)	4.6	20	4.0	17	2.6	10
Lower limit 95% confidence interval GM	3.7	17	3.4	15	2.1	9
Upper limit 95% confidence interval GM	5.6	22	4.7	19	3.2	12
PFOS (µg/l)						
Minimum	−1.4	−53	−5.0	−76	−13.8	−39
Maximum	5.3	53	3.2	42	8.3	31
Geometric mean (GM)	0.5	9	0.6	10	0.9	8
Lower limit 95% confidence interval GM	0.3	6	0.4	8	0.7	6
Upper limit 95% confidence interval GM	0.8	14	0.8	14	1.1	10
PFHxS (µg/l)						
Minimum	−0.4	−22	n.c.	n.c.	−0.6	−21
Maximum	1.6	41	1.5	43	1.9	39
Geometric mean (GM)	0.1	9	0.1	11	0.3	11
Lower limit 95% confidence interval GM	0.08	7	0.1	9	0.2	9
Upper limit 95% confidence interval GM	0.17	13	0.2	13	0.4	14

Individual differences between first and second blood sampling date. Calculated as $PFC_{2006} - PFC_{2007}$. Time periods: 335 to 386 days (Median 359, $N = 288$). n.c. = not calculated.

fluorochemical production workers, Olsen et al. (2007) calculated a half-life of 3.5 years (geometric mean; 95%confidence interval: 3.0-4.1 years) for PFOA in the human body. The retired workers from the mentioned study had considerably higher serum PFOA-concentrations (mean: 691, range 72-5100 µg/l) compared to Arnsberg's residents in this study (2006; mean: 25-29, range 1-100 µg/l). It seems plausible, that background exposure from nonoccupational sources may influence the elimination rates to a greater extent in Arnsberg's residents because of their lower PFOA plasma levels. Emmett (2009) reported from the PFOA exposed community, Little Hocking, Ohio, USA, a median 26%decrease of PFOA serum levels after approximately 15 months follow up, which is comparable to our results.

There are some limitations to the study. Until now, blood concentrations of perfluorinated compounds only have been measured twice in Arnsberg's residents – approximately one year apart. The exact magnitude and duration of the drinking water contamination are unknown. Each individual of the study population had been exposed to elevated PFOA-concentrations in drinking water for several years until May-July 2006. After the contamination had been detected in May 2006 (Skutlarek et al., 2006), the PFOA-concentrations in drinking water measured by different laboratories ranged between 500 and 640 ng PFOA/l. There are no data available on PFOA-concentrations in Arnsberg's drinking water before May 2006. In July 2006, waterworks installed activated charcoal filtering and thus reduced the PFOA-concentrations in drinking water distinctly. Filter-performance exhausted with time and was restored by reactivation of the charcoal at regular intervals (approximately every 6 months). Reactivation of activated carbon is carried out in specialized reactivation centers and involves treatment in a high temperature furnace to over 800 °C. During filter maintenance work PFOA-concentrations in drinking water increased slightly for several weeks (Fig. 1). Questionnaire data indicate that Arnsberg's residents reduced their consumption of drinking water from public water supply distinctly after the contamination became known. This may have contributed also to the observed small reductions of the PFHxS-concentrations. Reduced fish consumption from local sources might also account for a decrease of the PFOS-concentrations. Additionally, the decline of the PFOS and PFOA-concentrations may at least partly reflect a decrease of PFC exposure in the general population. A likewise effect was shown by Calafat et al. (2007) for the internal PFC exposure of the US-population between the surveys 1999/2000 and 2003/4. No explanation was found for the slight increase in the PFOA-concentrations in 23 individuals.

Plasma samples of Arnsberg's residents will be analyzed in a further follow-up study to confirm the reported decline and to gain some insight into the elimination half-life of PFOA in Arnsberg's residents.

Acknowledgements

We gratefully acknowledge the children and adults, who contributed blood samples, and the staff from the health authorities Hochsauerlandkreis, especially Gudrun Befeld-Elkemann, Sibylle Behringer and Marco Wanke for their support. We thank Sonja Schaub and Johannes Müller for expert technical support.

The study was financed by the Ministry of Environment and Conservation, Agriculture and Consumer Protection, North Rhine-Westphalia, Germany.

References

ATSDR, 2008. Perfluorochemical contamination in Lake Elmo and Oakdale, Washington County, Minnesota. Retrieved 30.01.2009, from 〈http://www.health.state.mn.us/divs/eh/hazardous/sites/washington/lakeelmo/phaelmooakdale.pdf〉.

Calafat, A.M., Wong, L.Y., Kuklenyik, Z., Reidy, J.A., Needham, L.L., 2007. Polyfluoroalkyl chemicals in the US population: data from the National Health and Nutrition Examination Survey (NHANES) 2003–2004 and comparisons with NHANES 1999–2000. Environ. Health Perspect. 115, 1596–1602.

DWC, 2006. Drinking Water Commission (Trinkwasserkommission) of the German Ministry of Health at the Federal Environment Agency. Provisional evaluation of PFT in drinking water with the guide substances perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) as examples. Retrieved 29 January 2008, from 〈http://www.umweltbundesamt.de/uba-info-presse-e/hintergrund/pft-in-drinking-water.pdf〉.

Emmett, E.A., 2009. Community exposure to PFOA and health parameters. Reprod. Toxicol. 27, 411. doi:10.1016/j.reprotox.2008.11.009.

Emmett, E.A., Shofer, F.S., Zhang, H., Freeman, D., Desai, C., Shaw, L.M., 2006a. Community exposure to perfluorooctanoate: relationships between serum concentrations and exposure sources. J. Occup. Environ. Med. 48, 759–770.

Emmett, E.A., Zhang, H., Shofer, F.S., Freeman, D., Rodway, N.V., Desai, C., Shaw, L.M., 2006b. Community exposure to perfluorooctanoate: relationships between serum levels and certain health parameters. J. Occup. Environ. Med. 48, 771–779.

Fromme, H., Tittlemier, S.A., Volkel, W., Wilhelm, M., Twardella, D., 2009. Perfluorinated compounds – exposure assessment for the general population in Western countries. Int. J. Hyg. Environ. Health 212, 239–270.

Hölzer, J., Midasch, O., Rauchfuss, K., Kraft, M., Reupert, R., Angerer, J., Kleeschulte, P., Marschall, N., Wilhelm, M., 2008. Biomonitoring of perfluorinated compounds in children and adults exposed to perfluorooctanoate-contaminated drinking water. Environ. Health Perspect. 116, 651–657.

OECD, 2002. Hazard assessment of PFOS and its salts. ENV/JM/RD(2002)17/FINAL. Organisation for Economic Co-operation and Development.

Olsen, G.W., Burris, J.M., Ehresman, D.J., Froehlich, J.W., Seacat, A.M., Butenhoff, J.L., Zobel, L.R., 2007. Half-life of serum elimination of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in retired fluorochemical production workers. Environ. Health Perspect. 115, 1298–1305.

Olsen, G.W., Logan, P.W., Hansen, K.J., Simpson, C.A., Burris, J.M., Burlew, M.M., Vorarath, P.P., Venkateswarlu, P., Schumpert, J.C., Mandel, J.H., 2003. An occupational exposure assessment of a perfluorooctanesulfonyl fluoride production site: biomonitoring. Am. Ind. Hyg. Assoc. J. (Fairfax, VA) 64, 651–659.

Paustenbach, D.J., Panko, J.M., Scott, P.K., Unice, K.M., 2007. A methodology for estimating human exposure to perfluorooctanoic acid (PFOA): a retrospective exposure assessment of a community (1951–2003). J. Toxicol. Environ. Health A 70, 28–57.

Skutlarek, D., Exner, M., Färber, H., 2006. Perfluorinated surfactants in surface and drinking waters. Environ. Sci. Pollut. Res. Int. 13, 299–307.

Ubel, F.A., Sorenson, S.D., Roach, D.E., 1980. Health status of plant workers exposed to fluorochemicals – a preliminary report. Am. Ind. Hyg. Assoc. J. 41, 584–589.

Wilhelm, M., Kraft, M., Rauchfuss, K., Hölzer, J., 2008. Assessment and management of the first German case of a contamination with perfluorinated compounds (PFC) in the Region Sauerland, North Rhine–Westphalia. J. Toxicol. Environ. Health A 71, 725–733.