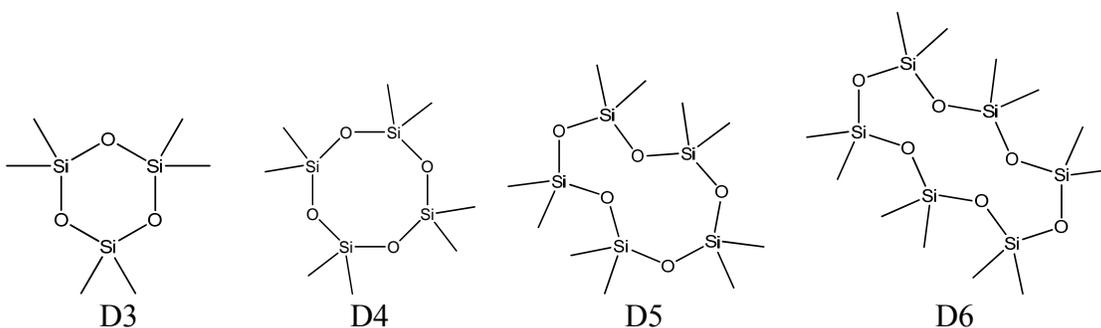


Cyclosiloxanes

Materials for the December 4-5, 2008 Meeting of the California Environmental Contaminant Biomonitoring Program (CECBP) Scientific Guidance Panel (SGP)

Agenda Item: "Consideration of Potential Designated Chemicals"

The siloxanes are chemicals that have a backbone structure of silicon and oxygen atoms, alternating in occurrence, and have hydrocarbon groups attached to the silicon side chain. In the cyclosiloxanes, the silicon-oxygen atoms are singly bonded and form a ring. Some widely used cyclosiloxanes are: hexamethylcyclotrisiloxane (D3), octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5) and dodecamethylcyclohexasiloxane (D6).



The cyclosiloxanes are used in the manufacture of silicones, in combination or alone in personal care products, and as carriers, lubricants and solvents in a variety of commercial applications. They occur in environmental media, especially in sewage sludge. In studies conducted by the Nordic countries, D5 was the dominant siloxane in all environmental matrices sampled except for air, where D4 dominated. Certain siloxanes are persistent in the environment, resisting oxidation, reduction, and photodegradation. Varying information exists on the susceptibility of siloxanes to hydrolysis. Some will be metabolized and the metabolites (hydroxylation metabolites) are expected to be found in blood and urine.

Because cyclosiloxanes are ubiquitous, special care is required to avoid the risk of contamination of samples during sample collection, storage and analysis. Evaporation or loss of the volatile siloxanes is also an analytical consideration. D3 is very volatile and subject to analytical difficulties. The necessary equipment to perform the analysis is available in the laboratory; however, method development and standards will be needed.

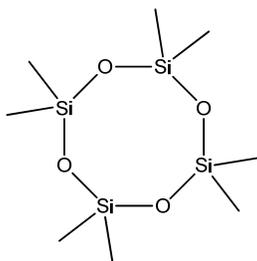
Need to assess efficacy of public health actions:

Cyclosiloxanes appear to be persistent and to have long half-lives in people. The weak estrogenic activity of D4, in combination with its long half-life, poses potential concerns for exposed individuals. While studies have not shown D5 to be estrogenic, it nonetheless increased uterine tumors in animal studies. In addition, there are potential concerns related to effects of D5 on the neurotransmitter dopamine and the hormone prolactin. Cyclosiloxanes are being touted as safer alternatives for a variety of uses, including D5 as a substitute for perchloroethylene in dry

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cleaning. It would be important to know if substitutes for existing chemicals are accumulating in the environment. Biomonitoring cyclosiloxanes could detect rising levels in humans, which would be of concern because of the evidence of biological effects associated with these chemicals. These measurements would be an important tool for evaluating the public health efficacy of substituting cyclosiloxanes as less toxic alternatives for other chemicals. This is an especially important question given new efforts under the California Green Chemistry Initiative to encourage the use of safer substitutes.

Additional information on D4, D5 and D6 follows.

Octamethylcyclotetrasiloxane (D4) [CAS No. 556-67-2]**Exposure or potential exposure to the public or specific subgroups:**

D4 is an intermediate in the manufacture of polydimethylsiloxanes, which are used in industrial and consumer (personal care and household products) applications including fermentation processes, instant coffee production, paper coatings and sizing, diet soft drinks, waste yeast tanks, food washing solutions, adhesives, textiles, de-asphalting, boiler treatments, detergents, cleaning solutions, surfactants, cosmetic products, and polishes. In combination with D5, D4 is used in the cosmetics and toiletries industry under the trade name cyclomethicone. Annual U.S. import/production volume of D4 was between 100 and 500 million pounds in 2002 (U.S. EPA 2002). D4 has been detected in wastewater streams (Mueller et al. 1995). Human exposures can occur when personal care products, cosmetics and other consumer products containing this substance are used, and potentially could also occur through environmental exposures (HSDB). Horii and Kannan (2008) used measurements of D4 in consumer products to estimate the daily exposure rate for women in the United States (ages 19-65) to D4 from the use of personal-care products as approximately 1 milligram (mg)/day.

Known or suspected health effects:

D4 animal toxicity studies found changes in organ weights (Burns-Naas et al. 2002, McKim et al. 2001a, He et al. 2003), induction of hepatic drug metabolizing enzymes (McKim et al. 1998), and adverse effects on reproductive health and function, including weak estrogenic effects (Stump et al. 1997 and 1999, He et al. 2003, Quinn et al. 2007a and 2007b, Siddiqui et al. 2007, Meeks et al. 2007; McKim et al. 2001b). D4 exposure has also been associated with the development of benign uterine tumors (adenomas) in rats (Plotzke et al. 2000). The acute LD50 of 6-7 g/kg indicates that D4 is acutely non-toxic (Lieberman et al. 1999).

Potential to biomonitor:***Physical and chemical properties:***

Vapor pressure: 1.05 mmHg at 25 °C.

Water solubility: 5.0×10^{-3} mg/L (5 ppm) at 25 °C.

Octanol/water partition coefficient: Log K_{ow} 5.1

Bioaccumulation: Bioconcentration factor (BCF) 12,400 L/kg

Persistence: Atmospheric degradation $t_{1/2}$ 13 days. Virtually no mobility in soil (K_{oc} 14,000) but some volatilization from moist and dry soil surfaces expected. If released into water, D4 adsorbs to suspended solids and sediment and estimated volatilization $t_{1/2}$ 1.8 hours (river); 6.8 days (lake); 120 days (pond).

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Past biomonitoring studies: The national survey of human adipose tissue conducted in 1982 analyzed 46 composite samples and qualitatively found D4 in 21 samples (U.S. EPA. 1987). Flassbeck et al. (2001) analyzed plasma and blood of women exposed to silicone gel filled implants (n = 14) and found that many years after the removal of ruptured silicone implants, D4 was present in the range of 14-50 ng/mL in plasma and 79-92 nanograms/milliliter (ng/mL) in blood. D4 was not detectable in plasma or blood of women without implants. In 3 women with silicone gel-filled implants, D4 was the most abundant siloxane found and was present at levels ranging from 11.9 - 1,300 nanograms/gram (ng/g) depending on the woman and the type of tissue sampled; no siloxanes were detected in control breast tissue samples (Flassbeck et al. 2003).

Availability of analytical methods: Hexane is used for extraction. The clear layer of the extract may be ready for High Resolution GC/ High Resolution MS (HRGC/HRMS). Metabolite analysis may be important. Several studies have measured cyclic siloxanes in human and rodent tissues, using gas chromatography coupled with an atomic emission detector (GC-AED) or mass spectrometric detector (GC-MS) (Kala et al. 1997; Flassbeck et al. 2001, 2003; Lykissa et al. 1997).

Availability of adequate biospecimens: Plasma and blood specimens. Highly lipophilic, metabolized by the liver, eliminated by exhalation and excretion – rates depend on the route of exposure (He et al. 2003). Major metabolites in rodents are dimethylsilanediol and methylsilanetriol (Varaprath et al. 1999, 2000).

Incremental analytical cost: Can be bundled with other cyclosiloxanes.

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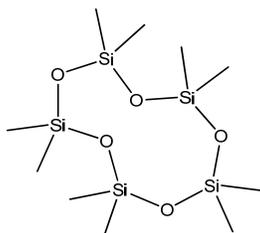
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Decamethylcyclopentasiloxane (D5) [CAS No. 541-02-6]**Exposure or potential exposure to the public or specific subgroups:**

D5 is used for industrial applications (silicone fluids and elastomers) and in a wide range of consumer products (cosmetics and toiletries). D5 is used as a dry cleaning agent, and has been marketed as a safer alternative to perchloroethylene. In combination with D4, D5 is used in the cosmetics and toiletries industry under the trade name cyclomethicone. U.S. production/import volume of D5 was between 100 and 500 million pounds in 2002 (U.S. EPA 2002). D5 has been detected in indoor and outdoor air (U.S. EPA 1992), in drinking water (Lucas 1984), in sediment (Norden 2005), and in emissions from urethane cushions (Shaeffer et al. 1996). D5 has also been detected in fish and other aquatic organisms (Mait 2005, Norden 2005). Horii and Kannan (2008) estimated total daily exposure to D5 from personal-care and consumer products in women (ages 19-65) in the United States as 233 milligrams (mg)/day.

Known or suspected health effects¹:

D5 has been shown to cause uterine endometrial adenocarcinomas in female rats (Dow Corning, 2005). D5 also has adverse health effects on the reproductive system, adipose tissue, bile production, and the immune system through its effects on prolactin, and it has the potential to cause adverse effects on the nervous system because of its influence on the neurotransmitter dopamine (OEHHA 2007). In contrast to D4, D5 has not been shown to have estrogenic effects (OEHHA 2007).

Potential to biomonitor:***Physical and chemical properties:***

Water solubility 0.017 – 0.05 mg/L at 25°C.

Vapor pressure 0.2 torr (mm Hg) at 25°C.

Octanol/water partition coefficient: Log K_{ow} = 5.2 – 5.71.

Bioaccumulation: Bioconcentration factor (BCF), bioaccumulation factor > 5,000 (Environment Canada 2007).

Persistence: D5 partitions into air, water, soil, and sediment, but mostly ends up in soil and sediment (Environment Canada, 2007). D5 half-life in air is 6.9 days (Atkinson 1989). The probability that D5 will biodegrade in water or soil is “essentially zero” according to Environment Canada (2007). An environmental monitoring study in Nordic countries found D5 to be the dominant cyclosiloxane in fish livers and marine mammals (Norden 2005). Animal experiments have shown that unchanged D5 is persistent in a “variety of tissues” for “extended periods of time;” the half-life in humans is measured in weeks, and “D5 may take a year to reach

¹ Summarized from 2007 OEHHA toxicity data review on D5

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steady state in fat tissue” (OEHHA 2007). OEHHA (2007) concluded that D5 “could accumulate in the environment, may bioconcentrate, and is a persistent substance.” Environment Canada (2007) concluded that D5 meets the persistence criteria for soils, sediments, and water.²

Past biomonitoring studies: A 1982 national survey of human adipose tissue found D5 in 28 of 46 people sampled (U.S. EPA 1987). Kaj et al. (2005) detected D5 levels as high as 4.5 micrograms/liter ($\mu\text{g/L}$) in human breast milk samples in Sweden. Flassbeck et al. (2001) showed an increase in the amount of low molecular weight cyclic siloxanes in blood of women with silicone breast implants, even several years after the removal of ruptured silicone implants [D5 28 ng/ml detected in one patient]. D5 was not detectable in plasma or blood of women without implants. Flassbeck et al. (2003) found levels of D5 as high as 637 ± 100 ng/g (~ 637 ppb) in the fat tissue of one woman who had a silicone gel-filled breast implant; no siloxanes were detected in control breast tissue samples.

Availability of analytical methods: Hexane is used for extraction. The clear layer of the extract may be ready for High Resolution GC/ High Resolution MS (HRGC/HRMS) to test for the parent compound which has been detected in human adipose tissue and breast milk.

Availability of adequate biospecimens: Plasma and blood. The metabolites in rat urine are methyl dimethylsilanediol [$\text{Me}_2\text{Si}(\text{OH})_2$] and methylsilanetriol [$\text{MeSi}(\text{OH})_3$] (Varaparth et al. 1999). No human data reported.

Incremental analytical cost: Can be bundled with other cyclosiloxanes.

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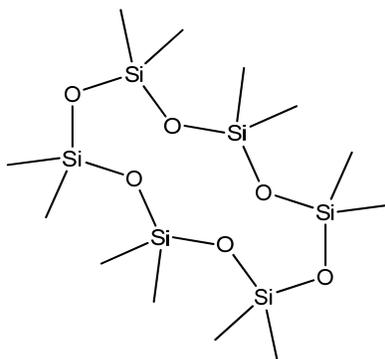
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Dodecamethylcyclohexasiloxane (D6) [CASRN: 540-97-6]¹³**Exposure or potential exposure to the public or specific subgroups:**

D6 is used in the production of consumer products and industrial products both as a raw material and as an intermediate in the production of silicone polymers. Silicone polymers are used to produce personal care products, pharmaceuticals, defoamers, surfactants, leveling agents, mold release agents, lubricants, cleaners, sealants, architectural coatings, mechanical, heat transfer and dielectric fluids, polishes and coatings. Annual U.S. production/import volume of D6 was between 10 and 50 million pounds in 2002 (U.S. EPA 2002). D6 has been detected in indoor and outdoor air (Kaj et al. 2005, Norden 2005), in drinking water (Lucas 1984), and in sewage sludge (Kaj et al. 2005, Norden 2005). Daily intake of D6 from a variety of sources was estimated by Environment Canada (2008) as ranging from 28.7 µg/kg bodyweight for persons 60 years and older to 87.0 µg/kg bodyweight for children 6 months to 4 years of age. Environment Canada (2008) estimated the upper limit of daily systemic dose of D6 from personal care products to be 100 µg/kg/body weight/day. Horii and Kannan (2008) measured the concentration of D6 in select consumer products (range 0.33 to 43,100 µg/g) and estimated daily exposure for women in the United States (ages 19-65) as 22,000 µg/day.

Known or suspected health effects⁴:

The liver is thought to be the target organ for oral exposures, and potentially for inhalation exposures (Environment Canada 2008). D6 exposure has been associated with liver and thyroid enlargement and reproductive effects (Dow Corning 2006). Model calculations suggest that D6 has the potential to affect aquatic organisms at concentrations close to its water solubility (Environment Canada 2008).

Potential to biomonitor:

Physical and chemical properties:

Vapor pressure 4 Pascal (0.03 mm Hg) at 25°C.

Water solubility 0.00513 mg/L at 23°C.

Octanol/water partition coefficient: log K_{ow} 4.36-9.06

³ D6 is also contained under another CAS No. (69430-24-6) which is associated with the following names: cyclopolydimethylsiloxane, cyclopolydimethylsiloxane (DX), cyclosiloxanes di-Me, dimethylcyclopolysiloxane, polydimethyl siloxy cyclics, polydimethylcyclosiloxane, cyclomethicone and mixed cyclosiloxane (Environment Canada 2008).

⁴ Summarized from 2008 Environment Canada review of D6

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Bioaccumulation: Bioconcentration Factor/Bioaccumulation Factor (BAF/BCF) > 5000.

Persistence: In comparison to D4 and D5, D6 has reduced aquatic bioavailability (Environment Canada 2008). The main environmental release of D6 is to air (78 percent) where most (99 percent) of it will remain ($t_{1/2}$ 6 days); of the D6 that ends up in water ($t_{1/2}$ > 180 days), 98 percent is adsorbed to suspended solids (sediment $t_{1/2}$ > 365 days). Almost 100 percent of the D6 that is released to soil remains in soil (soil $t_{1/2}$ > 180days) (Allen et al. 1997, Environment Canada 2008). Environment Canada (2008) concluded that with a biomagnification factor (BMF) of 20, D6 is “likely to biomagnify in terrestrial food chains.” It also concluded that D6 meets the criteria for persistence and bioaccumulation potential in air, water, and sediment.⁵

Past biomonitoring studies: A 1982 national survey of human adipose tissue found D6 in 28 of 46 people sampled (U.S. EPA 1987). Flassbeck et al. (2001) analyzed plasma and blood of women exposed to silicone gel filled implants (n = 14) and found that many years after the removal of ruptured silicone implants, D6 was present (17 ng/mL, ~ 17 ppb) in the plasma of one woman. D6 was not detectable in plasma or blood of women without implants. In 3 women with silicone gel-filled implants, D6 was present at levels ranging from 25.1-780 ng/g (~25-780 ppb) depending on the woman and the type of tissue sampled; no siloxanes were detected in control breast tissue samples (Flassbeck et al. 2003).

Availability of analytical methods: Method similar to those used for analyzing D4 and D5.

Availability of adequate biospecimens: Plasma and blood.

Incremental analytical cost: Can be bundled with other cyclosiloxanes.

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⁵ As set out in the 2000 Government of Canada Persistence and Bioaccumulation Regulations.

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