Silicon

(CAS No: 7440-21-3)

Health-based Reassessment of Administrative Occupational Exposure Limits

Committee on Updating of Occupational Exposure Limits,
a committee of the Health Council of the Netherlands

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1 Introduction

The present document contains the assessment of the health hazard of silicon by the Committee on Updating of Occupational Exposure Limits, a committee of the Health Council of the Netherlands. The first draft of this document was prepared by MA Maclaine Pont, M.Sc. (Wageningen University, Wageningen, the Netherlands).

Literature was retrieved from the databases Medline, Toxline, and Chemical Abstracts covering the periods 1966 until May 1999, 1981 until April 1999, and 1937 until April 1999, respectively, and using the following key words: silicon or 7440-21-3 (and (toxic*) not (silicone or silicon dioxide). The search for toxicological data on elemental silicon was hampered by a wealth of studies on silicon compounds, silica, silicones, silanes, using the entry silicon in their list of control terms, even using the CAS registry number for the elemental silicon.

In February 1999, the President of the Health Council released a draft of the document for public review. The committee received no comments.

An additional literature search in May 2002 did not result in information changing the committee's conclusions.

2 Identity

name	:	silicon
synonyms	:	-
atomic formula	:	Si
CAS number	:	7440-21-3

Natural silicon contains 3 isotopes. Fourteen other radioactive isotopes are recognised. Silicon makes up 25.7% of the earth's crust, by weight, and is the second most abundant element, being exceeded only by oxygen. Silicon is not found free in nature, but occurs chiefly as the oxide and as silicates. Silicon is prepared commercially by heating silica and carbon in an electric furnace, using carbon electrodes. Several other methods can be used for preparing the element (Lid96).

3 Physical and chemical properties

atomic weight:	:	28.08
melting point	:	1414ºC
boiling point	:	3265ºC
vapour pressure	:	at 1724ºC: 0.133 kPa
solubility in water	:	insoluble
log $P_{octanol/water}$	:	0.53 (estimated)
conversion factors (20ºC, 101.3 kPa)	:	not applicable

Data from Lew92, Lid96, http://esc.syrres.com.

Silicon occurs as gray crystals, or as a brown amorphous solid (Lid96). Silicon is attacked by halogens and dilute alkali. Most acids, except hydrofluoric acid, do not attack it (Lid96). Dust explosions are possible; their strength is much higher than can be expected from the rate of pressure rise (Luc94, Win95). Silicon undergoes spontaneous oxidation in air to form a thin layer of silica on the surface (Sch93).

4 Uses

Silicon is used in the synthesis of silanes and silicones; in the manufacture of transistors, silicon diodes, and similar semiconductors; it has been used in alloys, such as ferrosilicon and silicon copper, and as a reducing agent in high-temperature reactions. Organosilicon compounds have application as insecticides, rodenticides, herbicides, and pharmaceuticals, and the methyl and ethyl derivatives have industrial applications (ACG91).

Hyperpure silicon can be doped with boron, gallium, phosphorus, or arsenic to produce silicon for use in transistors, solar cells, rectifiers, and other solid-state devices which are used extensively in the electronics and space-age industries. Hydrogenated amorphous silicon has shown promise in producing economical cells for converting solar energy into electricity (Lid96).

5 Biotransformation and kinetics

The committee did not find data on the biotransformation and kimetics of silicon.

6 Effects and mechanism of action

Human data

A large, multidisciplinary investigation of reproductive and other health outcomes has been performed in the semiconductor industry. In this industry, many chemicals are used, like arsenic and arsenic compounds, glycol ethers, xylene, mixed hydrocarbons, hydrofluoric acid, halogenated hydrocarbons, Cl_2, BCl_3, CCl_4, $SiCl_4$, CF_4, SF_6, and others (Ede90, Sch95b). In 1995, the results of the study have been published. In none of the studies, possible exposure to silicon was indicated (Sch95a). Therefore, the committee cannot use these data to evaluate the risk of occupational exposure to silicon.

Human fetal lung cells showed dose-dependent cell necrosis and degeneration when incubated with a solution of 50-150 µg elemental silicon/mL (Yin82).

Animal data

A few investigations have been performed with elemental silicon, and several with welding dust, containing silicon.

Intratracheal instillation of 50 mg ultrapurified silicon in rats caused primarily pneumoconiosis in the alveoli. The toxicity of silicon dust is considered to be lower than that of quartz dust. After 3 months, the lung tissue showed silicostic nodules, made up of macrophages containing black Si dust particles (Gol78).

Intratracheal instillation of 25 mg elemental silicon induced slight pulmonary epithelial lesions after 12 months in rabbits (Sch71). In rats, 50 mg increased the relative lung weight after 12 months and introduced dust foci in the lungs, thickening of interalveolar septums, late and small development of fibrous connecting tissue in them, and bronchitis (Ark67).

Inhalation of 50 mg elemental silicon increased the redox potential in the lungs of rats, which was at its maximum on day 6. There were no further data (Pra80). Inhalation of 1.55 mg/m^3 in combination with radiant heat at 7.0 cal/cm^2 for 2 to 8 months increased the level of glycogen and decreased the level of lactate in the cornea of rats (Gmy75).

Injections of 100-200 mg elemental silicon (particle size <10 μ) per animal over a long period did not induce toxicity in rats and guinea pigs. The authors noted that the cellular changes were typical of inert responses (McC37).

The welding dusts, used in the animal experiments, contained various amounts of silicon (from 1.9 to 19.8%), and other elements, e.g., Fe, Mn, K, N, Ca, or F. In all studies, single doses of 50 mg of the dust were intratracheally administered to rats. Effects noted were: increased lipid peroxidation in lung and liver (Gel87, Gel89, Gel90), and modified albumins in blood serum (Bor88). After daily intratracheal instillation of 12.5 mg dust/kg bw for 1 month, haemodynamic and metabolic changes, morphological changes in macrophages, atelectasis, and emphysema were noted in the cardiac-respiratory system of rats (Pok90).

The committee did not find data from studies on carcinogenicity, genotoxicity, mutagenicity or reproduction toxicity of silicon.

7 Existing guidelines

The current administrative occupational exposure limit (MAC) for silicon in the Netherlands is 10 mg/m^3, 8-hour TWA.

Existing occupational exposure limits for silicon in some European countries and in the USA are summarised in the annex.

8 Assessment of health hazard

There is very little opportunity for occupational exposure to silicon in its elemental form. In metallurgy, silicon is heated in an oxygen atmosphere, resulting in oxidation to silicon dioxide (silica), before there is any potential for its volatilisation. Occupational exposure by inhalation and ingestion of mixed dusts containing silicon and silica may potentially occur during the manufacture of semiconductor-grade silicon and the manufacture of electronic equipment. However, these processes have to be carried out in very clean environments, and, as a result, exposures are minimised (Sch93).

After intratracheal administration of elemental silicon to rats, lung effects were found like pneumoconiosis, epithelial lesions, bronchitis, and fibrosis (Ark67, Gol78, Sch71), but from these data no target organ can be derived.

The committee considers the toxicological database on silicon too poor to justify recommendation of a health-based occupational exposure limit.

The committee concludes that there is insufficient information to comment on the level of the present MAC-value.

References

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Arb00a Arbejdstilsynet. Grænseværdier for stoffer og materialer. Copenhagen, Denmark: Arbejdstilsynet, 2000; At-vejledning C.0.1.

Arb00b Arbetarskyddsstyrelsen. Hygieniska gränsvärden och åtgärder mot luftföroreningar. Solna, Sweden: Arbetarskyddsstyrelsen, 2000; Ordinance AFS 2000:3.

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Luc94 Lucas J. Explosionsfähige Staub/Luft-Gemische. Bewertung von Explosionskenngrößen, die in verschiedenen Apparaturen ermittelt wurden. TU 1994; 35: 61-8.

McC37 McCord CP, Frederick WG, Stolz S. The toxicity of silicon. J Lab Clin Med 1937; 23: 278-9; cited from Chem Abstr 32: 5074d.

Pok90 Pokrovskaya TN, Cherednichenko, VM. [Effect of welding dusts on morphology of bronchopulmonary system and heart in experiment.] Russian. Gig Tr Prof Zabol 1990; 9: 37-40; cited from Chem Abstr 114: 1907k.

Pra80 Prager P, Puppi A, Zsoldos T, et al. [Changes of redox potentials in the lungs in connection with the inhalation of silicon powder.] Hungarian. Kiserl Orvostud 1980; 32: 378-80; cited from Chem Abstr 93: 231973f.

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Annex

Occupational exposure limits for silicon in various countries.

country -organisation	occupational exposure limit		time-weighted average	type of exposure limit	note[a]	reference[b]
	ppm	mg/m^3				
the Netherlands						
- Ministry of Social Affairs and Employment	-	10	8 h	administrative		SZW02
Germany						
- AGS	-	-				TRG00
- DFG MAK-Kommission	-	-				DFG02
Great Britain						
- HSE	-	10[c], 4[d]	8 h	OES		HSE02
Sweden	-	-				Arb00b
Denmark	-	10	8 h			Arb00a
USA						
- ACGIH	-	10	8 h	TLV		ACG02b
- OSHA	-	15[c], 5[d]	8 h	PEL		ACG02a
- NIOSH	-	10[c], 5[d]	10 h	REL		ACG02a
European Union						
- SCOEL	-	-				CEC00

[a] S = skin notation; which means that skin absorption may contribute considerably to the body burden; sens = substance can cause sensitisation.

[b] Reference to the most recent official publication of occupational exposure limits.

[c] Total inhalable dust.

[d] Respirable fraction.