THE CHEMICAL TOXICITY OF ELEMENTS

Battelle

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by

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Water and Land Resources Department

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THE CHEMICAL TOXICITY OF ELEMENTS

The continued growth of the nuclear industry has led to ever increasing volumes of high and low level radioactive wastes. Concomitant with the growing volumes of waste there has been a rising concern in the populace at large over the hazards posed by these materials. The major focus of this concern has been the radiological hazard inherent in waste materials. Little or no attention has been paid to the chemical toxicity of the diverse chemical species found in these materials. In light of the relatively long time frames associated with custodianship of radioactive wastes, it would appear appropriate to define the inherent chemical hazard of these materials and thereby gain a better understanding of those hazards which will influence the waste management process.

The following table and appended narrative enumerate the acceptable threshold levels for the 104 known elements in air and water intended for potable supply, propagation of aquatic life, and irrigation purposes. A final data point was added to indicate a limiting marine level beyond which edible species could concentrate elements to hazardous levels in their flesh.

It must be recognized that the state of knowledge on chemical toxicity varies greatly from element to element. For the most part, knowledge of acceptable body burdens and chronic administration levels is restricted to a very few elements. Consequently, it is necessary to estimate chronic exposure

thresholds from acute effect data or from chemical similitude to other elements for which toxicological data have been gathered. Such extrapolations are approximations at best and should be viewed as such. Reliability is of special concern when the element of interest can exist in several valence states, since acute toxicological data may be based on a form which is unstable in the body after a brief residence time. For instance, neptunium salts have been reported to be far less toxic upon standing than when first prepared. This suggests that a logical extension of the present work would involve an analysis of the Eh-pH characteristics of the elements to identify their stable state under conditions found in the human body, e.g., in the presence of blood and lipids.

It also should be recognized that the data are grouped for metals in various valence states which implies that the actual chemical species is not as important as the valence state. This approximation should hold for soluble inorganic forms and most insoluble forms. It will not necessarily hold for organic compounds. No attempt was made to address such species as methylmercury or the cacodylates.

With these limitations in mind, extrapolation techniques were derived to estimate acceptable levels of the 104 elements for chronic exposure when no other data were available. The basis upon which each threshold level was set is referred to in an adjoining column labeled "Basis." The letter code refers to the procedure followed to derive the threshold as outlined

in the appended notes. Numerical subcodes refer to specific nuances employed for the element in question and are also explained in the notes. A final column yields the reference from which the initial toxicological data were taken.

In developing the various "Basis" techniques employed to generate chemical toxicity thresholds, varying reliability surfaced as a function of the type of data that were available. The matrix below indicates the level of reliability placed in each of the techniques employed.

	<u>Reliability</u>		
	<u>High</u>	<u>Lower</u>	<u>Lowest</u>
General Basis Code	D	B	A
	E	C	K
	G	F	L
	I	M	M
	R	J	N
	V	P	O
		Q	S
		U	T

Because of the extrapolation techniques required to derive the **threshold** levels selected, it is emphasized again that many of these numbers are approximations at best. They are conservative for the most part. Therefore, they may be much more protective than limits normally established by regulatory agencies. More research on chemical action in the body and empirical toxicological testing is required to refine these data.

**DESIRED MAXIMUM AMBIENT ENVIRONMENTAL LEVELS FOR ELEMENTAL FORMS
BASED ON CHEMICAL TOXICITY**

Element	Form	Potable Water		Aquatic Life		Irrigation		Air		Concentration in Seawater		Bioconcentration in Marine Water		
		Basis	Ref	Basis	Ref	Basis	Ref	Basis	Ref	Basis	Ref	Basis	Ref	
Actinium	Trivalent	A-1	1	0.015	B-1	1	-	-	-	-	7x10 ⁻⁹	-	.005	
	Trivalent	E-1, E-2, D	8, 5	1.5	G	22	1.0	G	8	.15	5x10 ⁻¹	-	1.3	
Americium	Trivalent	A-17	10	-	-	-	-	-	-	-	7x10 ⁻²⁹	-	.05(.005)	
	Tetravalent	A-2	3	-	-	-	-	-	-	-	-	.00000025 (.000000025)	-	
Antimony	Trivalent	C, D	4, 5	2.0	B	1	-	-	0.005	F	6	5x10 ⁻²⁴	.03	
	Elemental	Q	14	-	-	-	-	-	33%	R	16	6x10 ⁻¹	-	
Arsenic	All Forms	E-1, E-2, D	8, 5	0.2	G	22	0.1	G	22	0.005	F	6	3x10 ⁻³	.017
	Univalent	J-1	1	1	J-1	1	-	-	0.01	J-1	6	1x10 ⁻²¹	25(.6)	
Astatine	Divalent	E-1, E-2, D	8, 5	0.3	G	22	1.0	G	9	0.005	F	6	3x10 ⁻²	8(.4)
	Divalent	A-3	10	-	-	-	-	-	-	-	-	7x10 ⁻²⁹	.0001(.00003)	
Berkelium	Trivalent	C	4	1.0	G	22	0.1	G	22	0.0001	I	4	1x10 ⁻⁵	.2
Beryllium	Divalent	D	5	-	-	-	-	-	0.0002	F-13	27	2x10 ⁻⁵	.08	
	Trivalent	D	5	-	-	-	-	-	-	-	-	2x10 ⁻⁵	.02	
Bismuth	Pentavalent	E-2	1	1.5	G	22	0.5	G	1	0.15	F	6	4.6	33(50)
	Trivalent	A-4	5	0.1	G	22	-	-	0.007	F	6	-	25	
Boron	Elemental	A	10	100	G	22	-	-	-	-	-	67	17	
	Univalent	A	10	-	-	-	-	-	-	-	-	-	80	
Bromine	Pentavalent	E-1, E-2, D	8, 5	0.0001	B	11	0.005	G	8	0.002	F-1	6	1x10 ⁻⁴	.004
	Divalent	G	1	1000	B	1	-	-	0.05	F-2	6	413	-	
Calcium	Divalent	A-8	10	-	-	-	-	-	-	-	-	7x10 ⁻²⁹	.002(.0002)	
Californium	Trivalent	E-3	8	0.1	G	1	-	-	0.55	F	6	-	-	
	Divalent	A	10	0.02	F	1	1.0	G-1	9	-	-	4x10 ⁻⁴	.5(.05)	
Carbon	Tetravalent	A-4	-	-	-	-	-	-	-	-	-	5x10 ⁻⁴	6	
	Trivalent	C	4	0.003	G	22	10	H	1	0.03	F	6	-	
Cerium	Univalent	E-1, E-2	8	50	G	8	100	G	7	-	-	19,400	-	
	Elemental	E-1, E-2	8	0.05	G	22	1.0	G	22	0.001	F	6	5x10 ⁻⁵	.003(.0006)
Cesium	Hexavalent	C, D	4, 5	1.0	G	1	0.2	G	12	0.001	F	6	1x10 ⁻⁴	.05(.03)
	Divalent	E-1, E-2, D	8, 5	0.2	G	8	0.2	G	8	0.001	F-1	6	3x10 ⁻³	.03(.013)
Chlorine	Univalent	E-1, E-2, D	8, 5	0.2	G	8	0.2	G	8	0.001	F-1	6	3x10 ⁻³	.03(.013)
	Divalent	E-1, E-2, D	8, 5	0.2	G	8	0.2	G	8	0.001	F-1	6	3x10 ⁻³	.03(.013)
Chromium	Hexavalent	E-1, E-2	8	0.05	G	22	1.0	G	22	0.001	F	6	5x10 ⁻⁵	.003(.0006)
	Divalent	C, D	4, 5	1.0	G	1	0.2	G	12	0.001	F	6	1x10 ⁻⁴	.05(.03)
Cobalt	Divalent	E-1, E-2, D	8, 5	0.2	G	8	0.2	G	8	0.001	F-1	6	3x10 ⁻³	.03(.013)
	Divalent	E-1, E-2, D	8, 5	0.2	G	8	0.2	G	8	0.001	F-1	6	3x10 ⁻³	.03(.013)
Copper	Divalent	E-1, E-2, D	8, 5	0.2	G	8	0.2	G	8	0.001	F-1	6	3x10 ⁻³	.03(.013)

DESIRED MAXIMUM AMBIENT ENVIRONMENTAL LEVELS FOR ELEMENTAL FORMS BASED ON CHEMICAL TOXICITY (Cont'd.)

Element	Form	Potable Water			Aquatic Life			Irrigation			Air			Concentration in Seawater			Bioconcentration in Marine Water		
		mg/l	Basis	Ref	mg/l	Basis	Ref	mg/l	Basis	Ref	mg/m ³	Basis	Ref	mg/l	Basis	Ref			
Curium	Trivalent	0.5	A-3	10	-	-	-	-	-	-	-	-	7x10 ⁻²⁹	-	-	.3(.03)	T-5	23	
Dysprosium	Trivalent	1.0	A	10	-	-	-	-	-	-	-	-	2x10 ⁻⁵	-	-	.2(.02)	T	23	
Einsteinium	Trivalent	0.01	A-9	10	-	-	-	-	-	-	-	-	7x10 ⁻²⁹	-	-	0.01(0.001)	T-5	23	
Erbium	Trivalent	0.1	A-4	10	-	-	-	-	-	-	-	-	6x10 ⁻⁶	-	-	0.03(0.003)	T	23	
Europium	Trivalent	0.2	A-4	10	-	-	-	-	-	-	-	-	8x10 ⁻⁶	-	-	0.05(0.005)	T	23	
Fermium	Trivalent	0.001	A-10	10	-	-	-	-	-	-	-	-	7x10 ⁻²⁹	-	-	.0003(.00003)	T-7	23	
Fluorine	Elemental	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Univalent	1.0,1.2, 1.5	E-1, E-2, D	8, 5	1.5	G	1	10	G	1	0.002 F	6	1.3	F	6	10	T	23	
Francium	Univalent	5.0	A-11	10	-	-	-	-	-	-	-	-	1x6 ⁻²²	-	-	6	T-8	23	
Gadolinium	Trivalent	0.2	A-4	10	0.015	B-1	1	-	-	-	-	-	3x10 ⁻⁵	-	-	0.1(0.01)	T	23	
Gallium	Trivalent	0.2	A-4	10	-	-	-	-	-	-	-	-	3x10 ⁻⁵	-	-	.02(.01)	T	23	
Germanium	Tetravalent	0.5	K	5	-	-	-	-	-	-	10	K	16	6x10 ⁻⁵	-	-	.004(.001)	T	23
Gold	Trivalent	0.02	A-12	10	-	-	-	-	-	-	33 ^W	R	16	3x10 ⁻⁵	-	-	.02	T	23
Hafnium	Tetravalent	0.05	A-4	10	10	B-2	1	10	H-1	1	0.005 F	6	6x10 ⁻⁶	-	-	.01(.001)	T-9	23	
Helium	Elemental	0.2	Q	14	-	-	-	-	-	-	-	-	5x10 ⁻⁶	-	-	-	-	-	
Holmium	Trivalent	1.0	A	10	-	-	-	-	-	-	-	-	5x10 ⁻⁶	-	-	.25(.025)	T	23	
Hydrogen	Univalent	pH 7.0, pH 6.0	E-1, E-2	8	pH 6.5	G	8	-	-	-	-	-	108,000	-	-	-	-	-	
Deuterium	Univalent	3,500	S	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Tritium	Univalent	3,500	S-1	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Indium	Trivalent	0.02	A-4	10	-	-	-	-	-	-	0.001 F	6	1x10 ⁻⁷	-	-	5x10 ⁻⁶	T	23	
Iodine	Univalent	10	J	1	1	G-2	1	-	-	-	0.01 F	6	6x10 ⁻²	-	-	25(.6)	T	23	
Iridium	Trivalent	0.8	A-4	10	-	-	-	-	-	-	-	-	1x10 ⁻⁸	-	-	0.2(.01)	T-10	23	
Iron	Trivalent	.05,0.3, 0.5	E-1, E-2, D	8, 5	0.2	G	1	5.0	G	22	0.01 F	6	1x10 ⁻²	-	-	.01	U	23	
Krypton	Elemental	40	Q	14	-	-	-	-	-	-	33 ^W	R	16	3x10 ⁻⁴	-	-	-	-	-
Lanthanum	Trivalent	1	A	1	0.015	B	1	-	-	-	-	-	3x10 ⁻⁴	-	-	.25(.025)	T	23	
Lawrencium	Trivalent	.01	A-13	10	-	-	-	-	-	-	-	-	-	-	-	.03(.003)	T-11	23	
Lead	Divalent	.01,.05, 0.1	E-1, E-2, D	8, 5	0.1	G	7	5.0	G	12	0.0015 F	6	5x10 ⁻³	-	-	0.16(0.05)	V-4	28	
Lithium	Univalent	5.0	G	1	0.005	G	22	0.075	G	22	-	-	0.17	-	-	2	T	23	
Lutetium	Trivalent	0.1	A-4	10	-	-	-	-	-	-	-	-	5x10 ⁻⁶	-	-	.03(.003)	T	23	
Magnesium	Divalent	10.29	E-1, E-2	8	1500	B	1	300	H	1	0.15 F-9	6	1294	-	-	1294	U	24	
Manganese	Univalent	.01,.05	E-1, E-2	8	0.1	G	22	2.0	G	8	0.05 F	6	0.002	-	-	0.002	U	24	
	Heptavalent	.01,.05	E-1, E-2	8	0.1	G	22	2.0	G	8	0.05 F	6	0.002	-	-	0.002	U	24	

DESIRED MAXIMUM AMBIENT ENVIRONMENTAL LEVELS FOR
ELEMENTAL FORMS BASED ON CHEMICAL TOXICITY (Cont'd.)

Element	Form	Potable Water		Aquatic Life		Irrigation		Air		Concentration in Seawater		Bioconcentration in Marine Water		Basis	Ref
		mg/l	Basis	mg/l	Ref	mg/l	Ref	mg/m ³	Ref	mg/l	Ref	mg/l	Ref		
Mendelevium	Trivalent	0.2	A-14	10	-	-	-	-	-	-	-	.05(.005)	T-12	23	-
Mercury	Divalent	0.002,0.005	E-4,D	21,5	0.01	G	7	-	0.0005	F	6	.0003	V	23	-
Molybdenum	Hexavalent	0.5	D	5	0.1	G	22	0.05, 0.15	F-3, F-4	6	6	1.3	T	23	-
Neodymium	Trivalent	0.2	A-4	10	0.015	B-3	1	-	-	-	-	.05(.005)	T	23	-
Neon	Elemental	1	Q	14	-	-	-	33%	R	16	16	1.4x10 ⁻⁴	-	-	-
Neptunium	Tetravalent	0.003	A-2	28	-	-	-	-	-	-	-	5x10 ⁻⁶ (5x10 ⁻⁷)	T-13	23	-
	Pentavalent	0.008	A-2	28	-	-	-	-	-	-	-	5x10 ⁻⁶ (5x10 ⁻⁷)	T-13	23	-
Nickel	Divalent	.05,0.1	C,D	4,5	0.05	G	7	0.5	12	0.01	F	.03(.01)	T	23	-
Niobium	Pentavalent	0.02	A	5	-	-	-	-	0.05	F	6	1x10 ⁻⁵	T	23	-
Nitrogen	Trivalent (Ammonia)	0.01,0.05	E-1, E-2	8	0.02	G	22	-	0.35	F	6	-.005	-	-	-
	Tetravalent (NO ₂)	-	-	-	-	-	-	-	0.09	F	6	-	-	-	-
	Pentavalent (Nitrate)	0.1,2-4	E-1, E-2	8	1000	B	1	-	-	-	-	-	-	-	-
Nobelium	Trivalent	0.1	A-15	10	-	-	-	-	-	-	-	.3(.03)	T-14	23	-
Osmium	Trivalent	1	A-16	13	-	-	-	-	-	-	-	.2(.01)	T-15	23	-
	Octavalent	-	-	-	-	-	-	0.00002	F	6	6	-	-	-	-
Oxygen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palladium	Divalent	0.05	M	5	0.07	B-4	1	-	-	-	-	.016(.0008)	T-15	23	-
Phosphorous	Elemental	0.1	G	22	0.01	G	22	-	0.001	F	6	-	-	-	-
	Pentavalent (Phosphate)	0.01,0.1	E-1, E-2	8	40	B	17	-	0.01	F-10	6	-	-	-	-
Platinum	Divalent	0.3	A-6	10	-	-	-	-	0.0002	F	6	1x10 ⁻⁵	T-16	23	-
Plutonium	Tetravalent	0.0008	A	28	-	-	-	-	-	-	-	5x10 ⁻⁷ (5x10 ⁻⁷)	T-17	23	-
Polonium	Tetravalent	0.2	K	-	-	-	-	-	0.001	F-12	6	1x10 ⁻¹³	T-21	23	-
	Hexavalent	1.0	K	-	-	-	-	-	0.001	F-12	6	1.2	T-21	23	-
Potassium	Univalent	1000-2000	E-2	1	50	G	1	-	-	-	-	-	-	-	-
Praseodymium	Trivalent	1.0	A	10	0.015	B-1	1	-	-	-	-	0.3(0.03)	T	23	-
Promethium	Trivalent	1.0	A-1	1	0.015	B-1	1	-	-	-	-	0.3(0.03)	T-18	23	-
Protactinium	Trivalent	0.005	A-5	10	-	-	-	-	-	-	-	.000004(1x10 ⁻⁷)	T	23	-
	Pentavalent	0.01	A-5	10	-	-	-	-	0.05	F-6	6	.00002(5x10 ⁻⁷)	T	23	-
Radium	Divalent	0.001	A-18	10	-	-	-	-	-	-	-	.00001(.000005)	T	23	-
Radon	Elemental	500	Q	14	-	-	-	33%	R	16	16	1.4x10 ⁻¹⁴	-	-	-

DESIRED MAXIMUM AMBIENT ENVIRONMENTAL LEVELS FOR
ELEMENTAL FORMS BASED ON CHEMICAL TOXICITY (Cont'd.)

Element	Form	Potable Water			Aquatic Life			Irrigation			Air			Concentration in Seawater			Bioconcentration in Marine Water		
		mg/l	Basis	Ref	mg/l	Basis	Ref	mg/l	Basis	Ref	mg/m ³	Basis	Ref	mg/l	Basis	Ref	mg/l	Basis	Ref
Rhenium	Trivalent	10	A-4	10	-	-	-	-	-	-	-	-	-	8.4x10 ⁻⁶	-	-	25(3.0)	T-19	23
	Heptavalent	50	A-4	10	-	-	-	-	-	-	-	-	-	-	-	-	125(15)	T-19	23
Rhodium	Trivalent	0.05	A	10	-	-	-	-	-	-	0.001	F-5	6	1x10 ⁻⁶	-	-	.013(.0008)	T-15	23
Rubidium	Univalent	5	A	10	2	B	1	-	-	-	0.00001	F-3	6	-	-	-	-	-	-
Ruthenium	Trivalent	1	A-4	13	-	-	-	-	-	-	-	-	-	.12	-	-	13(7)	T	23
Samarium	Trivalent	0.2	A-4	10	-	-	-	-	-	-	0.00002	F-7	6	1x10 ⁻⁶	-	-	0.2(.01)	T	23
Scandium	Trivalent	0.5	K	10	-	-	-	-	-	-	-	-	-	5x10 ⁻⁵	-	-	.05(.005)	T	23
Selenium	All	<0.01,0.01	E-1, E-2	8	<0.01	G	1	0.02	G	22	0.002	F	6	4x10 ⁻⁵	-	-	.1(.01)	T	23
														1x10 ⁻³	-	-	.016	U	24
Silicon	Tetravalent (Silicates)	5	A	10	50	P	1	10-50	G	10	0.76 M11 F	Particulates/ cu.m.	6	3	-	-	60(4)	T	23
Silver	Univalent	.001,.05	E-1, E-2	8	0.01	G	7	-	-	-	0.0001	F	6	3x10 ⁻⁴	-	-	.0003	U	24
Sodium	Univalent	1000	G-3	7	500	B-5	1	70	H	1	0.02	F	6	10,800	-	-	-	-	-
Strontium	Divalent	10	A	14	200	B-4	1	-	-	-	-	-	-	8	-	-	500(40)	T	23
Sulfur	Divalent	0	D	5	0.002	G	22	-	-	-	0.15	F	6	-	-	-	-	-	-
	Tetravalent	-	E-1, E-2	8	-	-	-	-	-	-	0.13	F	6	-	-	-	-	-	-
	Hexavalent	50,250	-	-	-	-	-	-	-	-	.01	F	6	812	-	-	-	-	-
Tantalum	Elemental	-	-	-	-	-	-	-	-	-	0.05	F	6	-	-	-	-	-	-
	Pentavalent	1.0	A	5	-	-	-	-	-	-	-	-	-	-	-	-	.3	T-20	23
Technetium	Trivalent	100	A-7	10	-	-	-	-	-	-	-	-	-	1x10 ⁻¹⁵	-	-	250(30)	T-3	23
	Heptavalent	500	A-7	10	-	-	-	-	-	-	-	-	-	1x10 ⁻¹⁵	-	-	1250(150)	T-3	23
Thulium	Tetravalent	0.2	K	5	-	-	-	-	-	-	0.001	F	6	5x10 ⁻⁵	-	-	.25	T-21	23
	Hexavalent	1.0	K	5	-	-	-	-	-	-	0.001	F	6	-	-	-	1.5	T-21	23
Terbium	Trivalent	0.5	A-3	10	-	-	-	-	-	-	-	-	-	5x10 ⁻⁶	-	-	0.1(0.01)	T-21	23
Thallium	Univalent	0.005	C	4	0.1	G	22	10	H	1	0.001	F	6	1x10 ⁻⁶	-	-	.0001	U	24
Thorium	Tetravalent	0.0005	A-4	10	0.1	B	1	10	H	1	5.0	L	5	5x10 ⁻⁵	-	-	.002(.00005)	T	23
Thuleium	Trivalent	0.2	A-4	10	-	-	-	-	-	-	-	-	-	5x10 ⁻⁶	-	-	.05(.005)	T	23
Tin	Divalent	0.05	C	4	1.0	N	1	-	-	-	0.02	F	6	3x10 ⁻³	-	-	.003	U	24
Titanium	Trivalent	0.1	D	5	12	B	1	1.2	H	1	Nuisance Particle	-	-	1x10 ⁻³	-	-	.003(.03)	T	23
Tungsten	Elemental	100	K	1	-	-	-	-	-	-	.01,.05	F-3, F-4	6	-	-	-	100	T	23
	Hexavalent	500	A	10	50	B	1	-	-	-	.01,.05	F-3, F-4	6	1x10 ⁻⁴	-	-	500	T	23
Uranium	Uranyl	<0.5,5.0	E-1, E-2	8	10	B	1	-	-	-	0.002	F	6	3x10 ⁻³	-	-	12.5(.5)	T	23

DESIRED MAXIMUM AMBIENT ENVIRONMENTAL LEVELS FOR
ELEMENTAL FORMS BASED ON CHEMICAL TOXICITY (Cont'd.)

Element	Form	Potable Water		Aquatic Life		Irrigation		Air		Concentration in Seawater		Bioconcentration in Marine Water		Ref
		mg/l	Basis	Ref	mg/l	Basis	Ref	mg/m ³	Basis	mg/l	Ref	mg/l	Basis	
Vanadium	Tetravalent	0.1	D	5	0.5	G	22	-	-	-	-	.25(.1)	T	23
	Pentavalent	0.1	D	5	0.5	G	22	0.0005, F-1	F-9, F-1	2x10 ⁻³	6	.25(.1)	T	23
Xenon	Elemental	150	Q	14	-	-	-	33%	R	1x10 ⁻⁴	16	-	-	-
Ytterbium	Trivalent	0.1	A-4	10	-	-	-	-	-	6x10 ⁻⁶	-	.3(.03)	T	23
Yttrium	Trivalent	0.001	A-4	10	-	-	-	0.01	F	3x10 ⁻⁴	6	.0003	U	24
Zinc	Divalent	0.05, 5.0, 1.0	E-1, E-2, D	8, 5	0.1	G	7	0.05, 0.01	F-9, F-10	1x10 ⁻²	6	.01	U	24
	Divalent	1.0	A	1	10	B	-	0.05	F	3x10 ⁻⁴	6	.25(.025)	T	23

APPENDIX

NOTES ON THE BASIS BY WHICH CHEMICAL TOXICITY THRESHOLDS WERE SELECTED

The following notes describe the basis method by which chemical toxicity thresholds were selected. Numerical subnotes within each category reflect nuances employed in dealing with a specific element.

METHOD A

Method A was employed when only acute median lethal dose (LD₅₀) and biological half-life data could be obtained. The rationale for the approach is based on the premise that if sufficient amounts of the element of interest are introduced in drinking water each day to accumulate in the body to an amount equivalent to the LD₅₀ value listed for the element, then a hazard exists in terms of chronic exposure. It is assumed that the element maintains its valence state throughout its residence in the body. Obviously, the validity of this assumption varies with the element being considered.

The amount of daily exposure that leads to a body burden equivalent to that resulting from application of the LD₅₀ is calculated by determining the cumulative amount C from an infinite period of exposure to the limiting concentration A₀ such that:

$$C = \int_0^{\infty} A_0 e^{-\ln 2(t/t_0)} dt$$

where

t = period of exposure in days

t₀ = biological half-life of the element in days

The infinite time span was selected to represent indefinite exposure of a whole population. After integration this simplifies to:

$$C = \frac{A_o t_o}{\ln 2}$$

and hence A_o , the daily allowable dose, can be calculated from:

$$A_o = \frac{C \ln 2}{t_o} = \frac{B \ln 2}{t_o}$$

where

B = the empirically derived oral LD₅₀ value for the element of interest in the valence state of concern

The daily dose, taken from LD₅₀ data, is given in terms of mg/Kg body weight. For the purposes of conversion to drinking water limits, a 100 Kg man with a daily consumption of 2.5 liters of water is assumed. Finally, a safety factor of 100 is applied so that actual doses will accumulate to 1/100 the LD₅₀ value level over the indefinite exposure period. The safety factor is applied to account for several factors:

- Undesirable sublethal effects may occur at levels much lower than the LD₅₀.
- The LD₅₀ represents the level at which 50 percent of the sample group dies. It is desirable to protect more than 50 percent of the population.
- LD₅₀ analysis is conducted with laboratory animals, and not on human subjects.

A tacit assumption throughout this development is that the degree of absorption into the body is the same per dose during chronic exposure as for the empirical LD₅₀ evaluation. This appears to be reasonable.

Subnotes to Method A

1. Level is based on the toxicity of chemically similar lanthanum.
2. Level is based on the toxicity of chemically similar plutonium.
3. Level is based on the toxicity of chemically similar terbium.
4. The LD₅₀ data available was derived from intraperitoneal, rather than oral, application.
5. Level is based on the toxicity of chemically similar tantalum.
6. Level is based on the toxic oral dose to rats rather than the LD₅₀.
7. Level is based on the toxicity of chemically similar rhenium.
8. Level is based on the toxicity of chemically similar dysprosium.
9. Level is based on the toxicity of chemically similar holmium.
10. Level is based on the toxicity of chemically similar erbium.

11. Level is based on the toxicity of chemically similar cesium.
12. The LD₅₀ data available was derived from intravenous rather than oral application.
13. Level is based on the toxicity of chemically similar lutetium.
14. Level is based on the toxicity of chemically similar thulium.
15. Level is based on the toxicity of chemically similar ytterbium.
16. Level is based on the toxicity of chemically similar ruthenium.
17. Level is based on the toxicity of chemically similar europium.
18. Level is based on subcutaneous administration rather than oral.

METHOD B

Method B is employed to translate acute aquatic toxicology data to an acceptable chronic threshold level when no chronic exposure data exist. The chronic limits are taken as 1/10 the 96-hour median threshold limit (TL_m) as prescribed by Pickering and Gast.² This factor was derived empirically in tests with several heavy metals. It is considered quite reliable for many elements. Some authors suggest that a factor of 1/100 is more appropriate for some elements,²² but this has not been well substantiated.

Subnotes for Method B

1. Level is based on the toxicity of chemically similar lanthanum.
2. Level is based on the toxicity of chemically similar hafnium.
3. Level is based on an initial data point derived from a 72-hour threshold rather than a 96-hour TL_m .
4. The 96-hour TL_m was estimated as 1/10 of an empirically determined 24-hour lethal level.

METHOD C

These levels have been set as a result of chronic application studies reported by Hazelton Laboratories.⁴

METHOD D

Thresholds given by Method D are those published as drinking water standards in the Soviet Union.

METHOD E

Thresholds given by Method E are those recommended by the U.S. Federal Water Quality Administration for U.S. waters.

Subnotes for Method E

1. Level is that listed as desirable for surface waters used for water supply.
2. Level is that listed as permissible for surface waters used for water supply.
3. Level is based on the limits set for alkalinity.
4. Level is that presently proposed for use in regulating waters for public water supply.

METHOD F

Method F was employed to translate levels presently regulated as threshold limit values (TLV) into acceptable ambient levels for continuous exposure. TLV limits are set for exposure over an eight-hour working day. These eight-hour limits are divided by a factor of 100 as prescribed by Hazelton Laboratories,⁴ and thus translated to 24-hour exposure limits.

Subnotes for Method F

1. Level is based on the TLV for metal dust and soluble salts.
2. Level is based on the TLV for calcium oxide.
3. Level is based on the TLV for soluble salts.
4. Level is based on the TLV for insoluble salts.
5. Level is based on the TLV for metal fume and dusts.
6. Level is based on the TLV for chemically similar tantalum.
7. Level is based on the TLV for chemically similar osmium tetroxide.
8. Level is based on the TLV for metal fume.
9. Level is based on the TLV for oxide fume.
10. Level is based on the TLV for phosphoric acid.
11. Level is based on the TLV for chloride fume.
12. Level is based on the TLV for chemically similar tellurium.
13. Level is based on the maximum allowable concentration (MAC) rather than the TLV.

METHOD G

Thresholds derived through Method G are those recommended by the referenced author.

Subnotes for Method G

1. Level is based on thresholds recommended by chemically similar aluminum.
2. Level is based on effects to the invertebrate daphnia.
3. Level is that recommended for used with livestock.

METHOD H

Method H was employed to derive limits for irrigation water based on limited observations of injury to plants. The calculation employed set the limit at 1/10 the lowest level at which damage to plants has been noted.

Subnotes for Method H

1. Level is based on the level selected for chemically similar thorium.

METHOD I

These levels are the proposed U.S. emission standards.

METHOD J

Method J was devised to translate epidemiological observations to an acceptable chronic level. The threshold was selected as 1/10 the lowest dose capable of producing iodism in sensitive individuals (300 mg/day).

Subnotes for Method J

1. Level is based on the toxicity of chemically similar iodine.

METHOD K

Method K was devised to translate observations on sublethal effects to chronic exposure thresholds. This was accomplished

by employing a safety margin factor of 10 to the lowest level at which sublethal effects have been noted.

Subnotes for Method K

1. Level is based on the toxicity of chemically similar tellurium.

METHOD L

This threshold was set based on a level found to have no effects during a one-year exposure period.

METHOD M

Method M was devised to translate data from studies of tumorigenesis into chronic exposure thresholds. The level was set as 1/100 the lowest level at which exposed animals began to develop an abnormal number of tumors.

METHOD N

This threshold was selected on the basis of studies directed to identifying the lower toxic threshold for the element.

METHOD O

This threshold was selected as 1/100 the level identified as the lethal dose.

METHOD P

This threshold was set at the level at which turbidity resulting from the silicates becomes a hazard in its own right.

METHOD Q

Method Q was derived in terms of physical properties rather than chemical-toxicological ones since the noble gases

have not been shown to have effects on organisms. The level selected here is the solubility of the gas in water at one atmosphere. The presence of gas in excess of this amount would constitute supersaturation and could have subsequent deleterious effects if consumed prior to establishment of equilibrium.

METHOD R

These levels are based on the threshold of effects for simple asphyxiants in air.

METHOD S

Method S was derived to account for recent observations in experiments with deuterium. It has been found that deuterated water cannot be tolerated in complete replacement of light water in body fluids.²⁰ The threshold level is therefore set as 1/100 the level at which replacement causes death.

Subnotes for Method S

1. Level is based on that set for deuterium.

METHOD T

Method T was employed to calculate concentrations in seawater which could be tolerated by marine life without concentration of the element to toxic levels. The calculation was based on the premise that daily intake of the element through consumption of fish should not exceed that allowed in drinking water. Hence, the potable water threshold was multiplied by 2.5 liters to yield the daily quantity limit. An average intake

of 0.1 Kg fish per day was then assumed,²⁶ and concentration factors gathered for the various organisms. The acceptable limit in seawater was then calculated as outlined below:

$$\text{Threshold} = \frac{\text{DWS} \left(\frac{\text{mg}}{\ell \text{ water}} \right) \times 2.5 \left(\frac{\ell \text{ water}}{\text{day}} \right)}{0.1 \left(\frac{\text{Kg fish}}{\text{day}} \right) \times \text{Cf}}$$

where

DWS = established drinking water standard

Cf = Dimensionless concentration factor for marine
organism of interest

This simplifies to:

$$\text{Threshold} = \frac{25 \text{ DWS}}{\text{Cf}}$$

The concentration factors were obtained from the literature or derived as the ratio of ambient concentrations in various marine organisms to the ambient level in the sea. The primary threshold given refers to fish. That in parenthesis refers to invertebrates and is given when the threshold for invertebrates differs from that for fish.

Subnotes for Method T

Concentration factors employed were those calculated for the referenced element on the basis of chemical similarities.

1. Lanthanum
2. Europium
3. Iodine

4. Dysprosium
5. Gadolinium
6. Holmium
7. Erbium
8. Cesium
9. Zirconium
10. Rhodium
11. Lutetium
12. Thulium
13. Promethium
14. Ytterbium
15. Ruthenium
16. Palladium
17. Samarium
18. Neodymium
19. Technetium
20. Niobium
21. Selenium

METHOD U

When concentration factors could not be employed to determine acceptable levels, the ambient level in ocean water was used as the threshold.

METHOD V

Method V is the preferred basis for deriving marine threshold limits. Here, FDA guidelines for residues in food are employed rather than drinking water standards to estimate acceptable daily intakes. The calculation thus becomes:

$$\text{Threshold} = \frac{\text{FDA Limit}}{C_f}$$

Subnotes for Method V

FDA limit is that prescribed as:

1. Maximum permissible for certain foods;
2. Tolerance limits for bromide in vegetables;
3. Established limits for most foods in Britain; and
4. Established limits for certain foods in Canada.

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