Trace Elements in Foundry Sands: A Comparison with Background Soil Concentrations

Robert S. Dungan and Rufus L. Chaney
USDA-Agricultural Research Service

Nicholas T. Basta and Elizabeth A. Dayton
The Ohio State University, School of Environ. and Nat. Res.

Overview of Presentation

- ARS program
- Spent foundry sands and beneficial use
- Trace elements in soils
- Characterization of elements in spent foundry sands
- Guidance limits for spent foundry sands in soil-related applications

Beneficial Use Guidelines for Spent Foundry Sands

- USDA-ARS research on the beneficial use of spent foundry sands initiated in 2003
- Address agricultural and horticultural uses
- Collaborative effort between USDA-ARS, USEPA-OSW, OSU, PSU, and Purdue University
- Ultimate goal is to produce a guidance document that can assist state regulatory agencies in developing or improving existing beneficial use regulations
- Ensure human and environmental protection
- A draft of the beneficial use guidelines has been completed and will shortly undergo peer review

Spent Foundry Sands in the United States

- The foundry industry uses 100 million tons of sand each year to create metalcasting molds and cores
- About 10 million tons of spent sand are generated
- Bulk of this material is green molding sand from ferrous and aluminum foundries
- Majority of spent molding sands are classified as non-hazardous waste (i.e. not corrosive, ignitable, reactive, and toxic)
- Discarded in municipal and private landfills; often used as daily cover

Spent Foundry Sands

Spent Foundry Sand Components

- Sand (> 85% by weight)
- Bentonite clay
- Crushed bituminous coal (seacoal)
- Gilsonite
- Cellulose
- Residual core material

Beneficial Use of Spent Foundry Sands

- Molding sands are selected for their unique physical and chemical properties
- High quality aggregate being diverted to landfills
- Component in manufactured soils
  - Topsoils, potting soils, and landscaping mixes
- Geotechnical applications
  - Flowable fill, asphalt, and cement
- Only 10% of spent sands are being beneficially used outside the foundry

Trace Elements in Soils

- Some trace elements are needed in minute quantities for the proper growth, development, and physiology of flora and fauna
- Boron, Cobalt, Copper, Iron, Iodine, Manganese, Molybdenum, Nickel, Selenium, and Zinc
- Naturally occurring in the mineral and organic phases of soils
- Trace element levels can become elevated in soils due to anthropogenic activities (e.g. non-ferrous metal smelting, burning fossil fuels, waste incineration)
- Natural events such as forest fires, volcanoes, and floods can redistribute elements and elevate soil levels

Yellow = Top 5 elements in the body

Green = Second top 5 elements

Blue = Micronutrients

Violet = Deleterious to humans

The Periodic Table of the Elements

1 H Hydrogen 1.00794																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Distribution of Arsenic in U.S. Soils

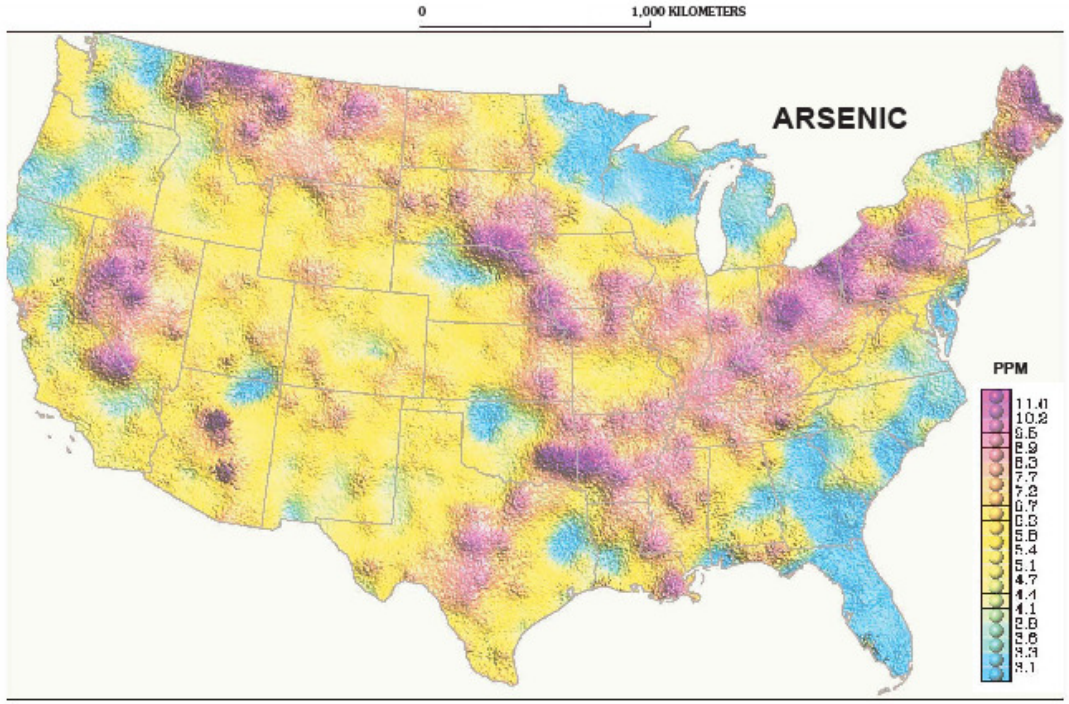

Figure 4. Colored surface map of As distribution in soils and other surficial materials of the conterminous United States.

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Gustavsson et al., 2001 (USGS report 1648)

Distribution of Copper in U.S. Soils

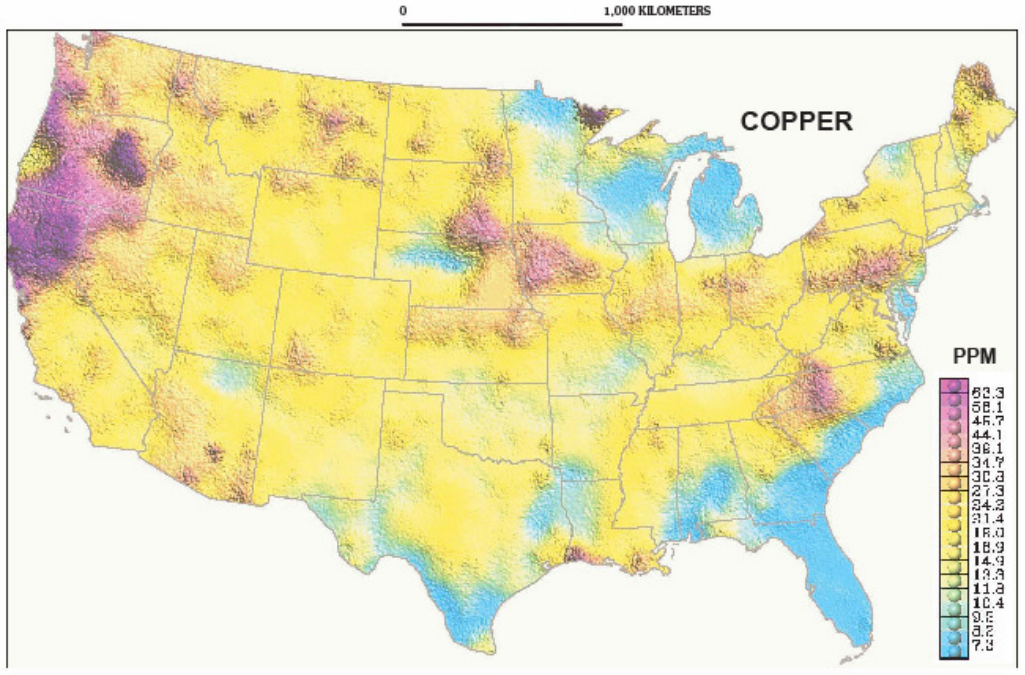

Figure 8. Colored surface map of Cu distribution in soils and other surficial materials of the conterminous United States.

Gustavsson et al., 2001 (USGS report 1648)

Distribution of Lead in U.S. Soils

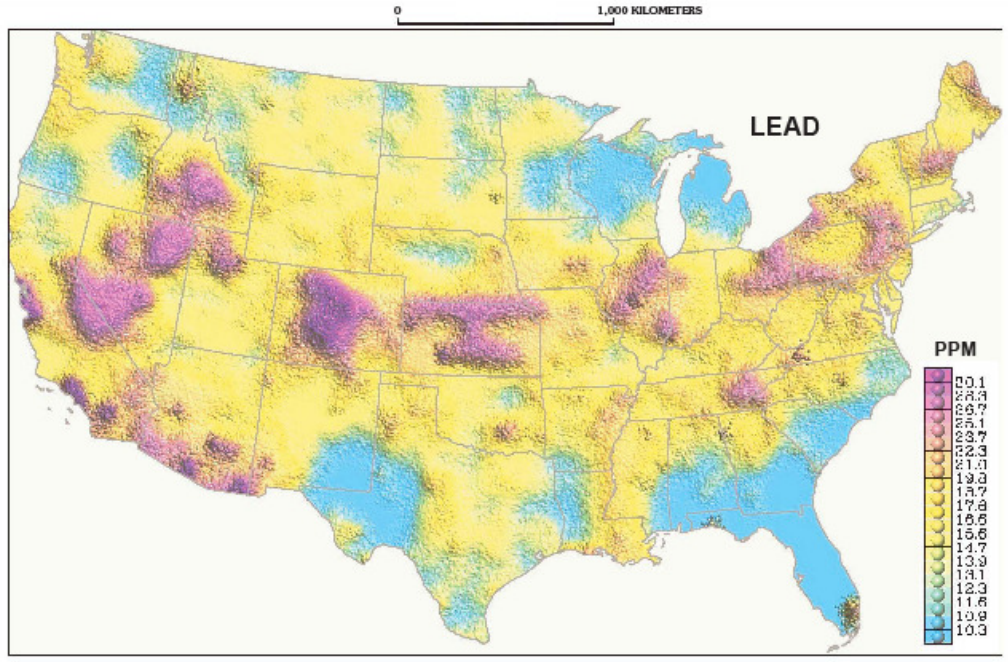

Figure 17. Colored surface map of Pb distribution in soils and other surficial materials of the conterminous United States.

Gustavsson et al., 2001 (USGS report 1648)

Distribution of Nickel in U.S. Soils

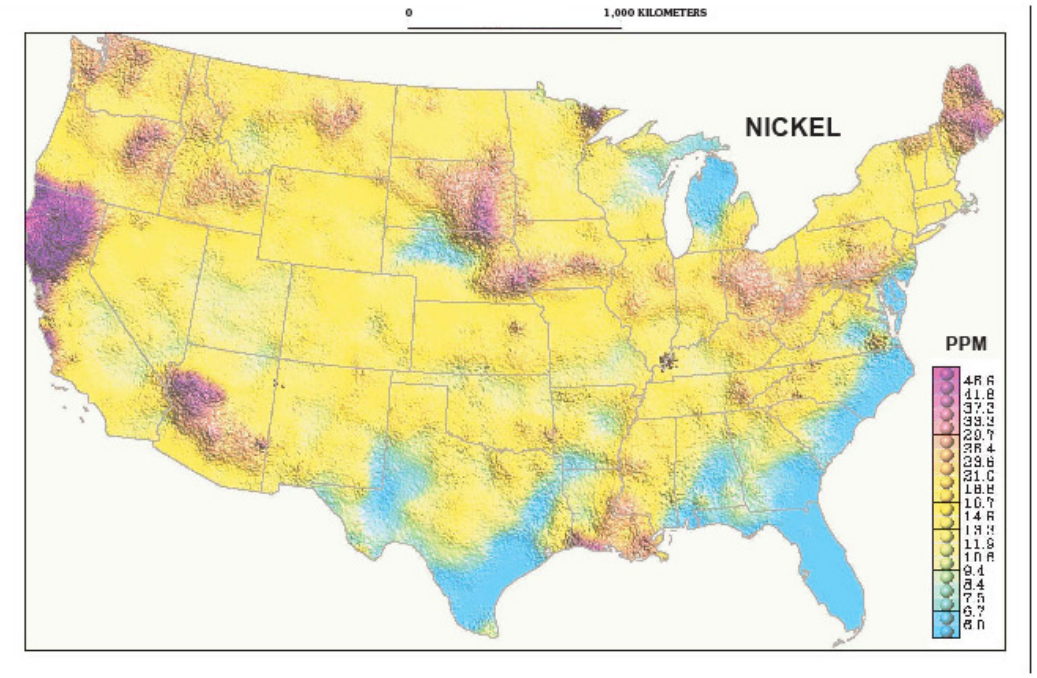

Figure 16. Colored surface map of Ni distribution in soils and other surficial materials of the conterminous United States.

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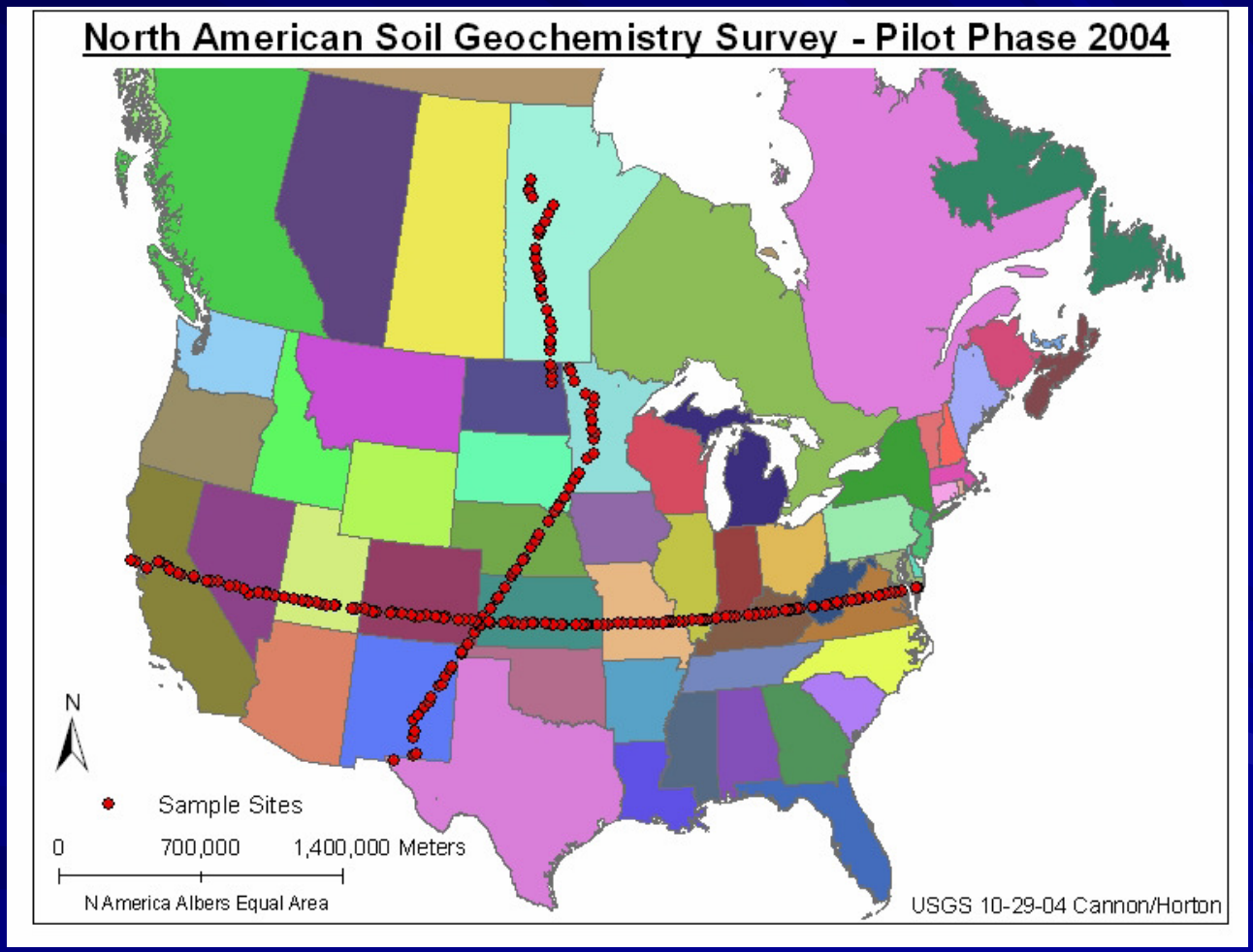
Gustavsson et al., 2001 (USGS report 1648)

Continental Transects of the U.S. and Canada



Smith et al., 2005 (USGS report 1253)

Element Concentrations in U.S. Soils (A horizon)

		(mg kg^{-1})		
Element	Min	Max	Mean	Median
Al	6900	87300	47500	47400
As	<1.	18	5.74	5
Ba	58	1800	529	526
Be	0.2	4	1.3	1.3
Ca	300	235700	18700	9050
Cd	<0.1	5.2	0.29	0.2
Co	0.9	143.4	8.93	7.1
Cr	3	5320	71.3	27
Cu	<0.5	81.9	14.3	12.7
Fe	3800	87700	20700	19200
Hg	<0.02	0.71	0.035	0.03
K	1200	43600	16400	15700
Mg	400	173400	7410	4600

Smith et al., 2005 (USGS report 1253)

Element Concentrations in U.S. Soils (A horizon)

		(mg kg^{-1})		
Element	Min	Max	Mean	Median
Mn	56	3120	610	490
Mo	0.11	21	1.03	0.82
Na	300	26400	8130	7400
Ni	1.6	2314	34.6	13.8
Pb	5.3	244.6	22.1	19.2
Sb	0.14	2.3	0.64	0.6
Se	<0.2	2.3	0.38	0.3
Sn	0.3	8.6	1.44	1.35
Sr	13	1382	184	156
Tl	<0.1	1.8	0.46	0.5
V	7	380	59.6	55
W	0.1	3.5	0.71	0.6
Zn	8	377	58	56

Smith et al., 2005 (USGS report 1253)

Foundry Sand Characterization

- Visited 37 foundries
- 13 states (east of Mississippi river)
- 43 sets of spent foundry molding sand collected
- June 2005, September 2005, and July 2006
- 31 iron, 6 steel, 4 aluminum, and 2 non-leaded brass
- 86% green sand
- Al, As, B, Ba, Be, Ca, Cd, Co, Cu, Cr, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Tl, V, Zn

Element Concentrations in Spent Foundry Sands

	(mg kg^{-1})			
Element	Minimum	Maximum	Mean	Median
Al	193	11725	4909	5125
As	0.13	7.79	1.61	0.99
B	10.0	59.4	11.4	10.0
Ba	5.0	141	11.1	5.00
Be	0.05	0.60	0.16	0.15
Ca	75	4090	1811	1830
Cd	0.02	3.79	0.16	0.06
Co	0.25	92.5	4.28	0.88
Cr	0.25	134	20.4	4.93
Cu	0.25	3805	110.4	7.04
Fe	540	64400	10300	4260
K	25.0	1780	375	321

Element Concentrations in Spent Foundry Sands

	(mg kg^{-1})			
Element	Minimum	Maximum	Mean	Median
Mg	50	286700	10719	1311
Mn	5.56	707	130	54.5
Mo	0.50	22.9	2.79	0.50
Na	10	1925	874	975
Ni	1.02	2560	101	3.47
P	5.41	176	52.2	49.5
Pb	0.50	22.9	4.62	3.63
S	25	2043	581	564
Sb	0.02	1.7	0.30	0.17
Se	0.06	59.5	1.60	0.20
Tl	0.02	0.1	0.04	0.02
V	0.50	11.3	3.34	2.88
Zn	5.0	2474	78.2	5.0

Element Concentrations in Olivine and Brass Sands

Element	units	Iron Green	Olivine 1	Olivine 2	Brass 1	Brass 2
Al	g/kg	0.219	3.44	1.70	0.650	5.14
As	mg/kg	0.126	0.395	0.498	0.223	2.09
B	mg/kg	<20	<20	<20	<20	<20
Ba	mg/kg	<10	<10	120	<10	<10
Be	mg/kg	<0.1	<0.1	<0.1	0.05	0.127
Ca	g/kg	0.285	1.09	1.32	0.075	1.69
Cd	mg/kg	<0.04	0.05	0.103	0.103	3.79
Co	mg/kg	<0.5	92.5	42.1	<0.5	<0.5
Cr	mg/kg	19.1	49.3	134	1.36	4.17
Cu	mg/kg	3.26	7.04	23.2	85.2	3805
Fe	g/kg	2.88	54.7	27.0	0.536	2.94
K	mg/kg	<50	321	203	<50	445
Mg	g/kg	0.103	287	124	0.060	1.39
Mn	mg/kg	14.1	639	570	14.0	18.7
Mo	mg/kg	<1	<1	2.49	<1	<1
Na	g/kg	<0.02	0.305	0.320	0.01	0.800
Ni	mg/kg	11.7	2560	1160	1.02	15.3
P	mg/kg	11.1	17.6	36.4	20.2	176
Pb	mg/kg	<1	3.03	2.55	1.79	20.8
S	g/kg	1.31	0.152	0.248	<0.05	0.545
Sb	mg/kg	0.15	0.094	0.11	0.10	0.74
Se	mg/kg	<0.4	<0.4	<0.4	1.15	59.5
Tl	mg/kg	<0.04	<0.04	<0.04	<0.04	0.065
V	mg/kg	<1	2.10	3.11	1.27	2.88
Zn	mg/kg	<10	46.3	26.0	34.7	2474

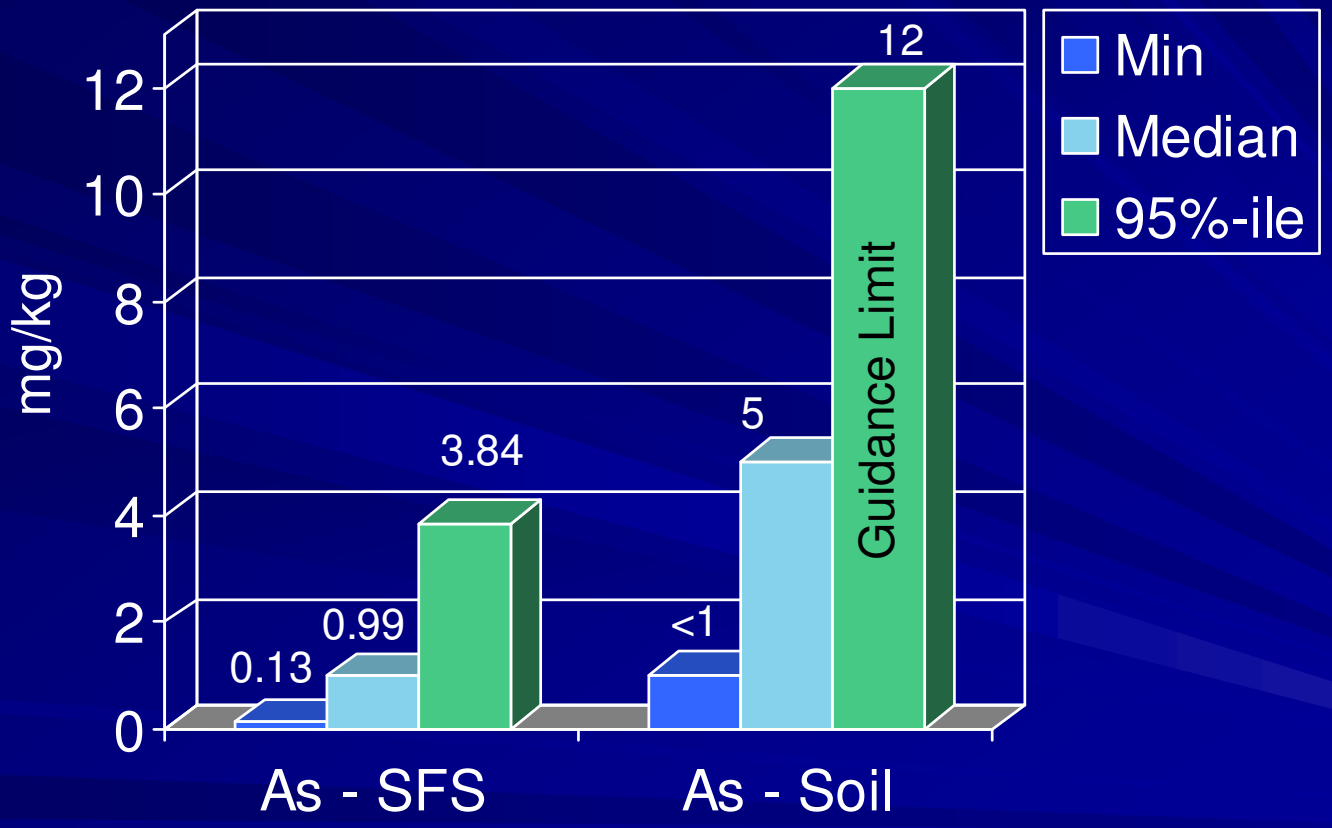
Guidance Limits for Elements in Spent Foundry Sands

- Trace elements are at low concentrations in iron, steel, and aluminum spent foundry sands
- A pathway risk assessment revealed that specific risk-based limits, based on adverse effect levels, could not be developed
- Based on the Smith et al. (2005) database, we suggest that spent sands contain no higher than the 95th percentile concentrations of background U.S. soils
- Beneficial use in manufactured soils or other soil-related applications presents no significant risk to humans or the environment

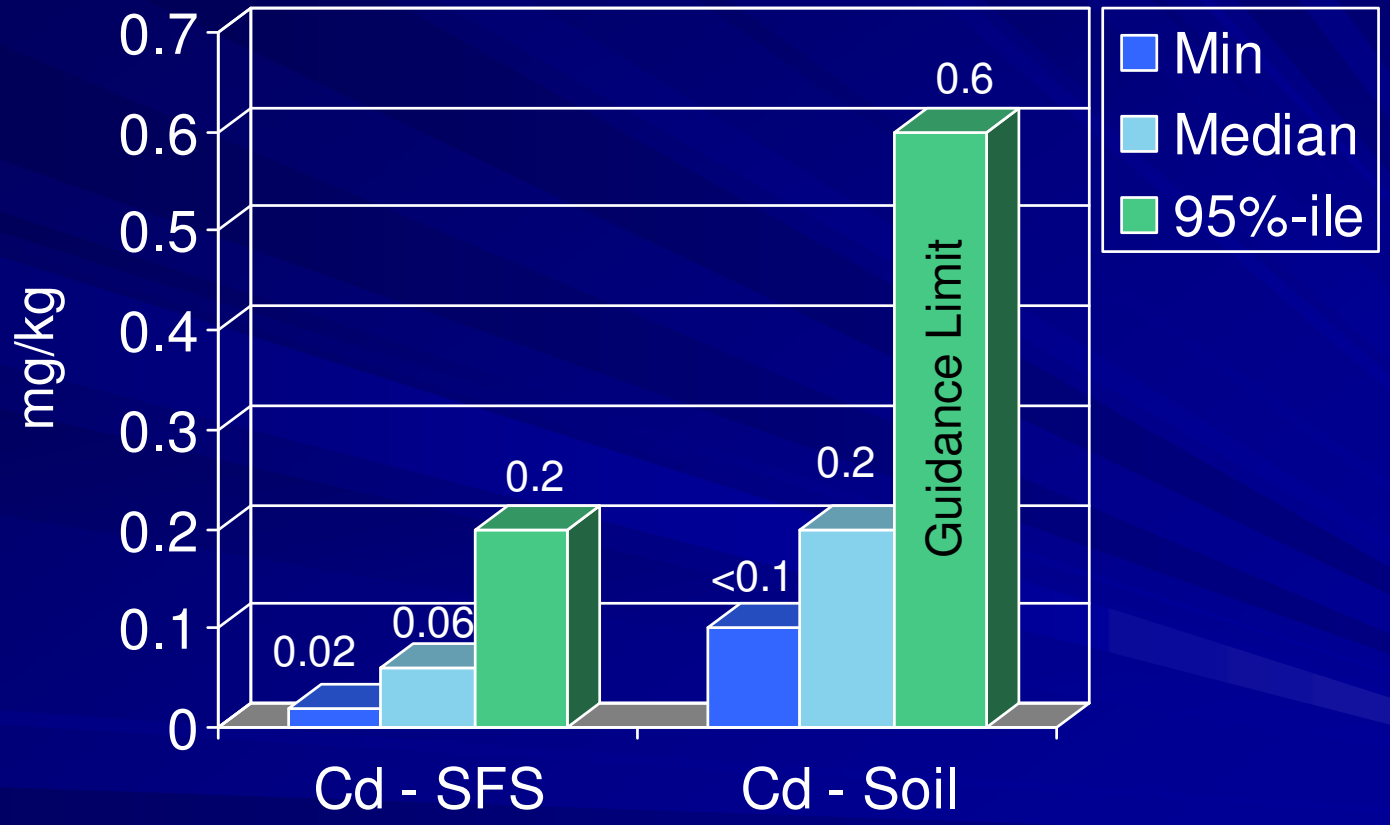
Guidance Limits for Elements in Spent Foundry Sands: Based on 95th Percentile of U.S. Soils

Element	mg kg^{-1}	Element	mg kg^{-1}
Al	74600	Mn	1630
As	12	Mo	2.2
Ba	840	Na	19400
Be	2.3	Ni	37.5
Ca	66600	Pb	38
Cd	0.6	Sb	1.39
Co	17.6	Se	1
Cu	30.1	Sn	2.5
Cr	70	Sr	458
Fe	42.6	Tl	0.7
Hg	0.08	V	119
K	28400	W	1.6
Mg	18800	Zn	103

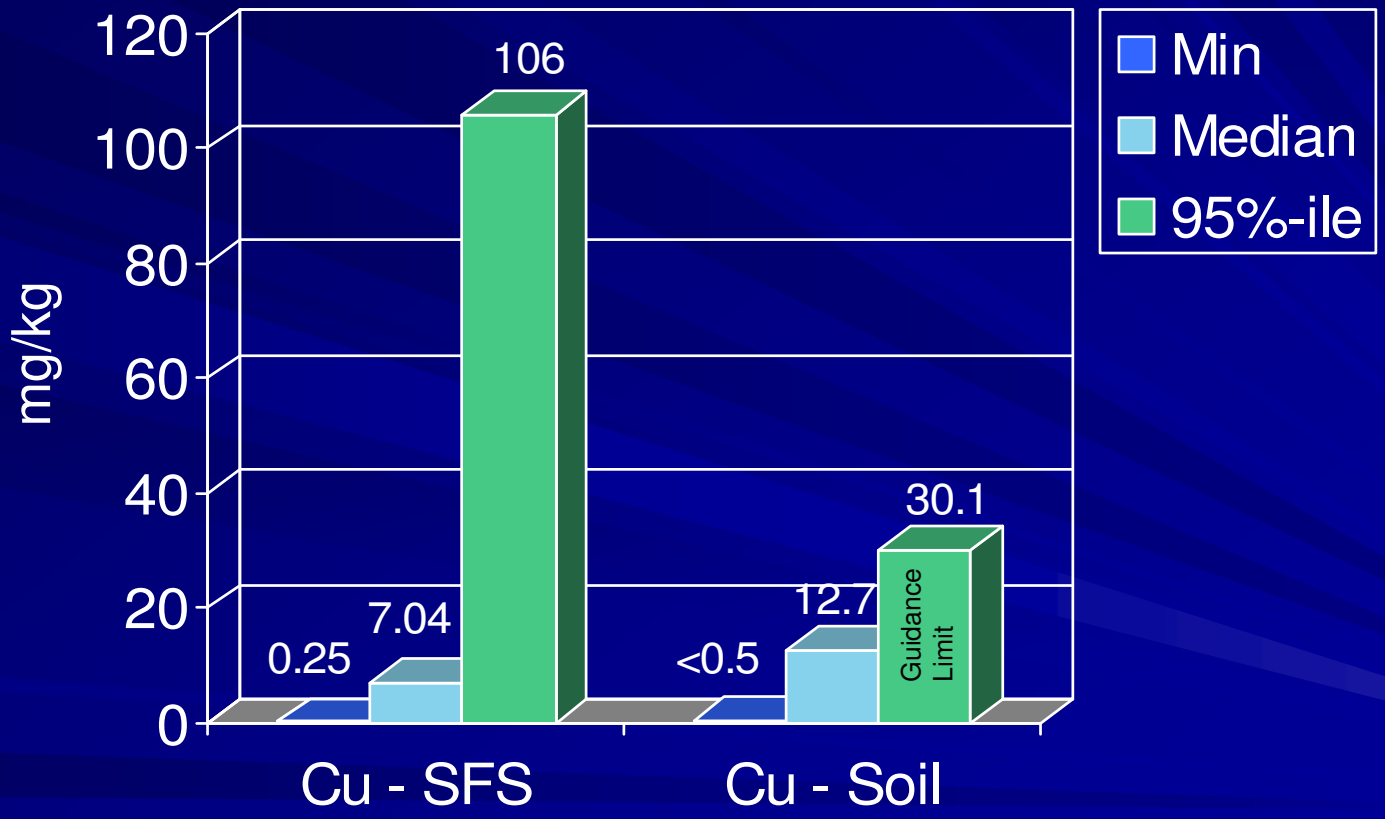
Arsenic in Spent Foundry Sands and Soils



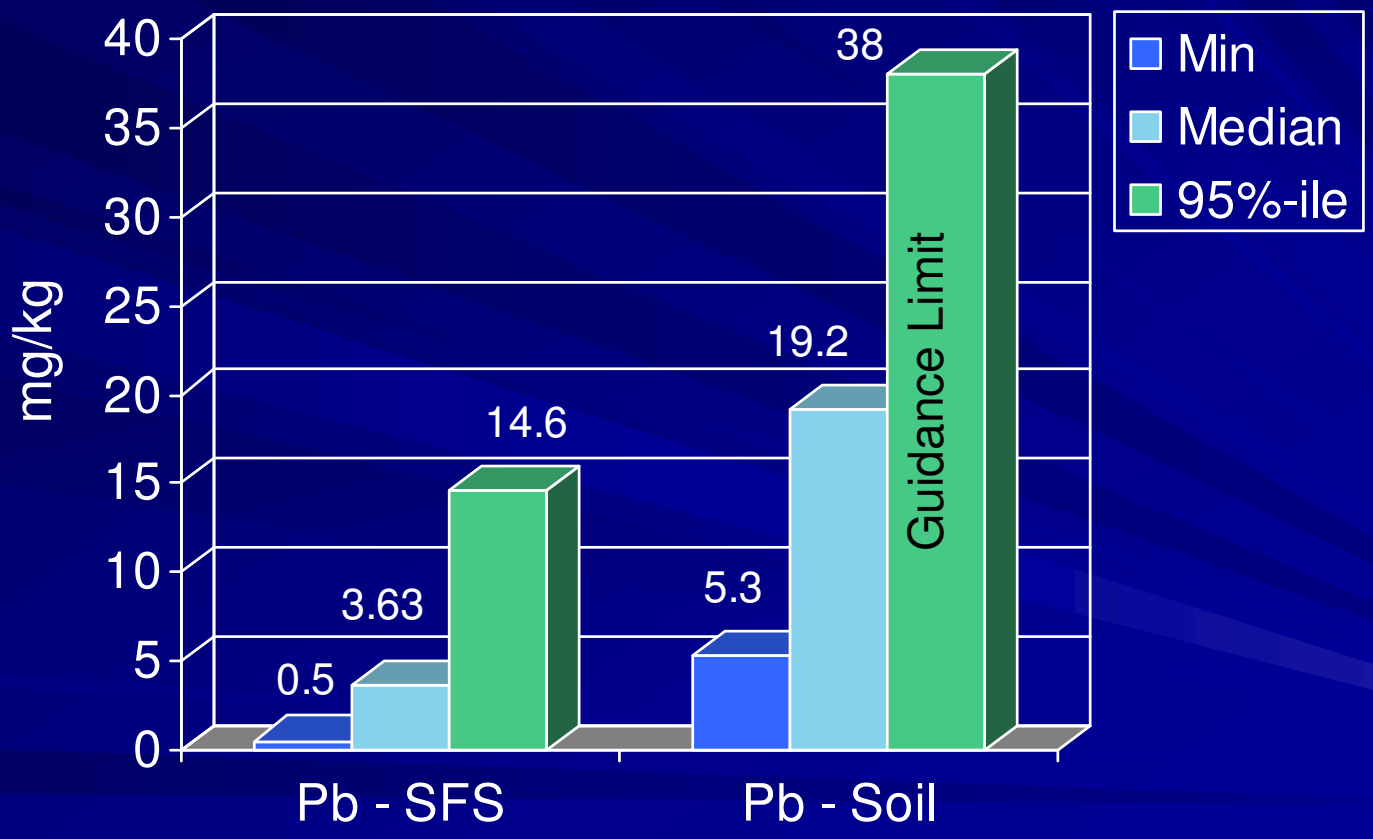
Cadmium in Foundry Sands and Soils



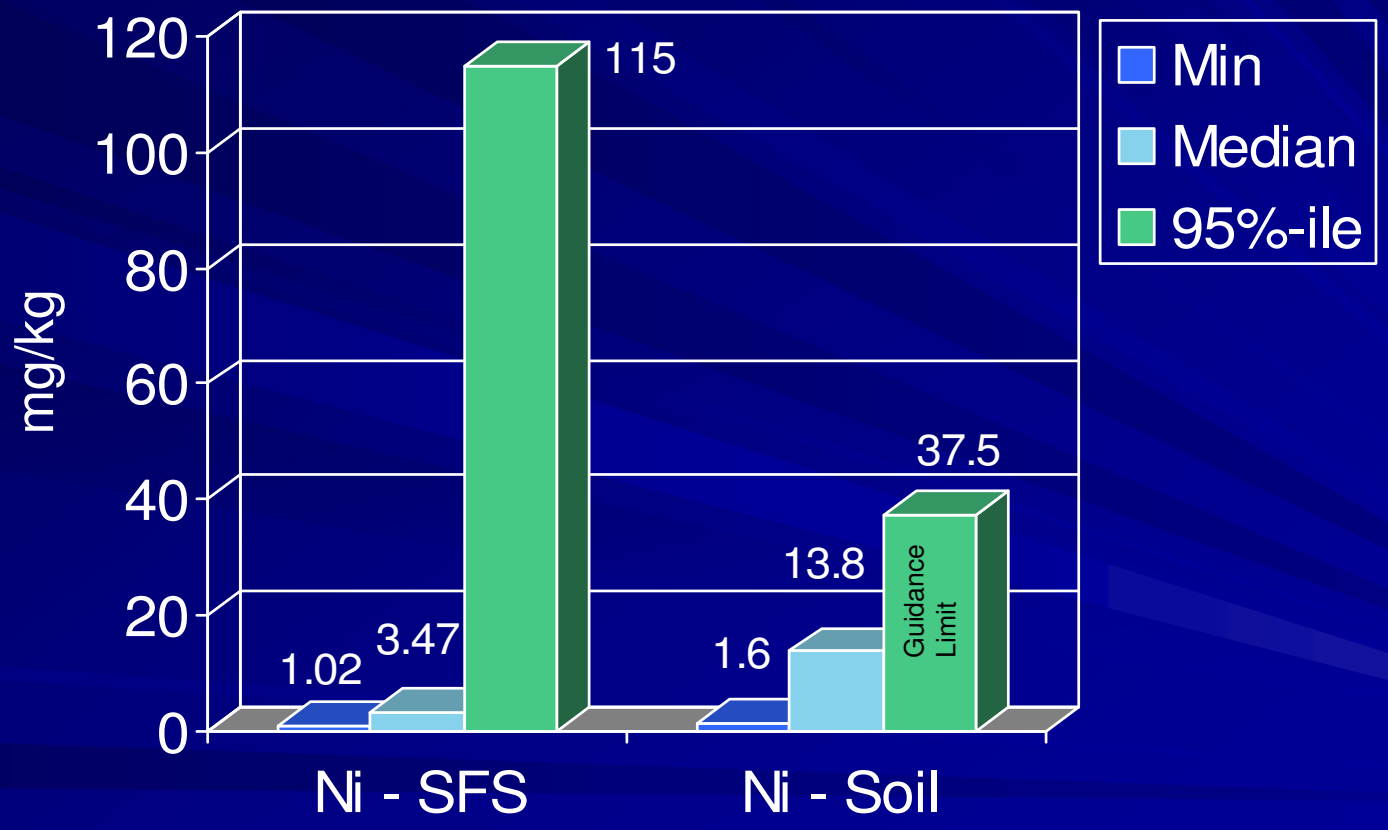
Copper in Foundry Sands and Soils



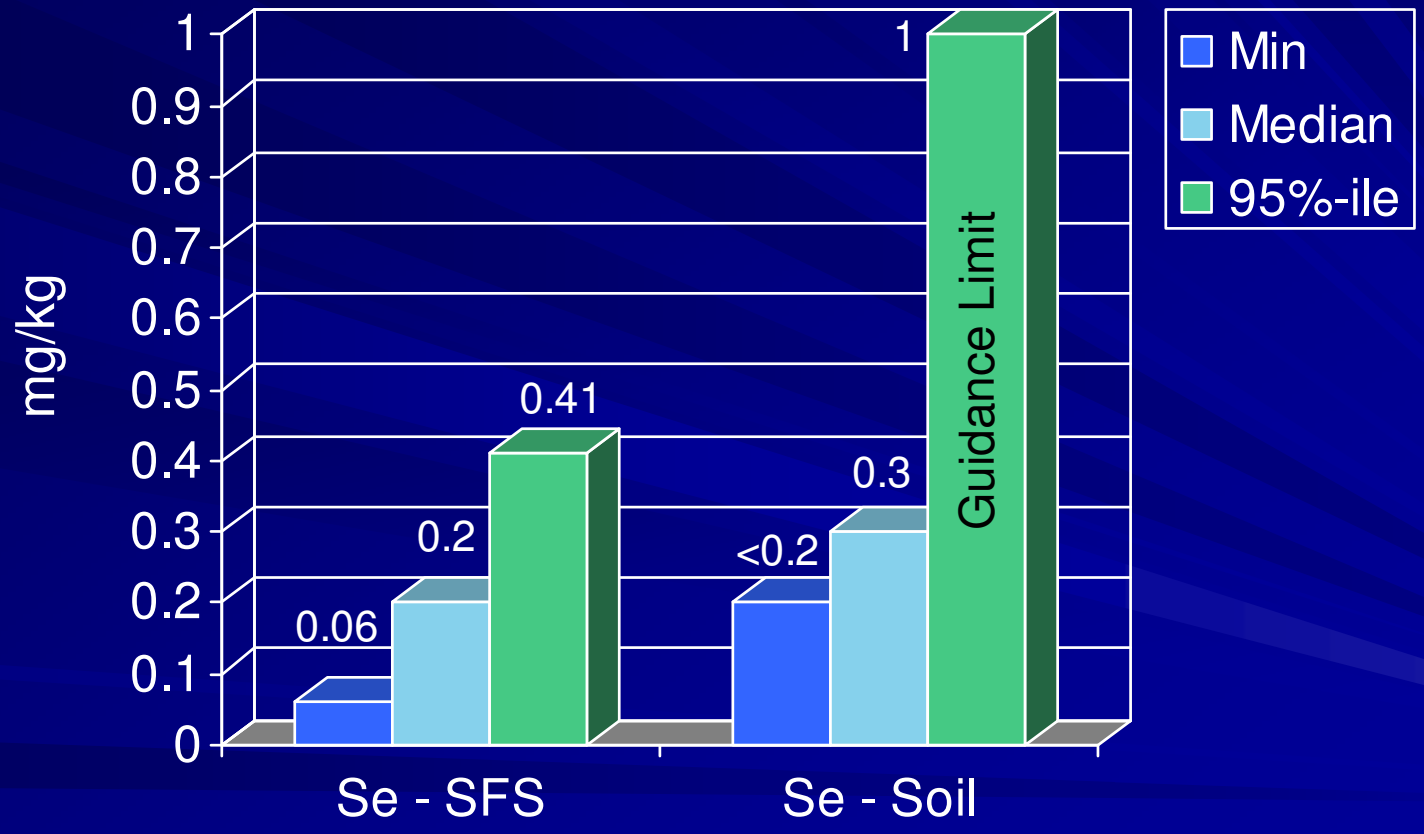
Lead in Foundry Sands and Soils



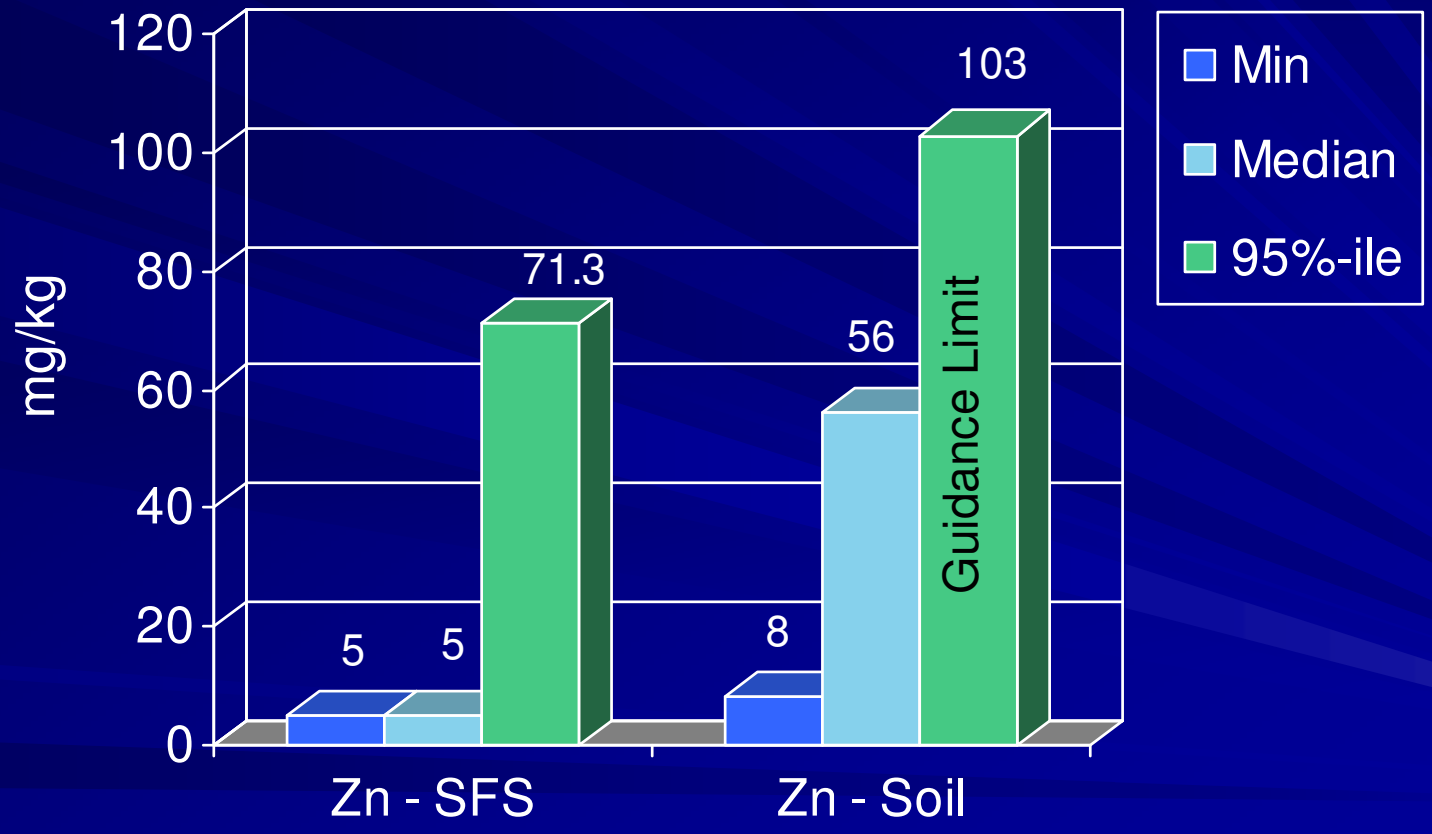
Nickel in Foundry Sands and Soils



Selenium in Foundry Sands and Soils



Zinc in Foundry Sands and Soils



Considerations

- Spent sands from brass and bronze facilities should not be considered for beneficial use in soil-related applications
- High Cu and Zn would likely cause phytotoxicity
- Olivine sands contain high Ni and are also a possible phytotoxicity risk
- Exceeding the 95th percentile concentrations does not mean it automatically fails, but a more thorough risk evaluation should be conducted
- Risk assessment approach could be applied to other byproducts