"Update on Research Findings and Regulatory/Legal Activities Regarding Tapwater Lead Exposure From Traditional Leaded-Brass and "No-Lead" Type Plumbing Parts"

Richard P. Maas, Ph.D., and Steven C. Patch, Ph.D.
UNC Asheville, Environmental Quality Institute

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I. INTRODUCTION AND BACKGROUND

A. Health Effects Related to Low Level Lead Exposure

Over the past 15 years the medical and scientific research community has been gradually uncovering the fact that even very low exposure to lead will cause permanent damage to the human neurologic system. Between 1987 and 1991, Bellinger, *et al.* (1987), McMichael, *et al.* (1988) and others (e.g., Needleman and Gastones, 1990; Schwartz, 1994) first discovered that infants and young children even with very low blood lead levels (BLLs) exhibited IQ and cognitive development index deficits (CDI). In the "Port Pirie Study" (McMichael *et al.,* 1988), it was observed that infants born with BLLs below 3 ug/dL scored higher on CDI tests at age four than infants born with blood lead levels (BLL) of 6-7 ug/dL or 10-12 ug/dL, even though the lead exposure of the three groups did not differ significantly after birth. Soon thereafter it was discovered that nine-year-olds with moderately elevated BLLs (10 ug/dL) had higher drop-out rates, behavior problems and criminal behavior later at age 19 than nine-year-olds with BLLs below 5 ug/dL, although again the two groups had similar lead exposures between ages nine and nineteen (Needleman *et al.,* 1990). Subsequently, numerous recent studies have found that low-level lead exposure not only causes IQ reductions but also causes learning disabilities, attention deficit disorder and aggressive behavior (Sciorello, *et al.,* 1992; Lappman, 2000). Most recently Lanphear in a major study (2001) found IQ and learning (especially reading) deficits in children (ages 6-16) with BLLs as low as 2.5 ug/dL. The Centers for Disease Control and Prevention (CDCP) has reviewed and validated this study, and the US EPA upon review of many studies has now officially adopted the position that there is no threshold dose below which lead does not cause neurologic damage in infants and young children. Thus, the US EPA (1991) has set a Maximum Contaminant Level Goal (MCLG) for lead in drinking water of zero. For modeling the effects of low-level lead exposure in infants and young children, the EPA and FDA have calculated a mean BLL increase of 0.16 ug/dL for each ug/day of lead ingested (FDA, 1993).

Various studies have found IQ deficits of 2-6 points for each 10 ug/dL increase in BLLs (Schwartz, 1994; Lanphear, 2001; FDA, 1993). Therefore, a young child drinking two liters/day of water with just 10 g/L of lead (i.e., 20 ug/day) would experience a BLL increase of approximately 3.2 ug/dL (1.3 IQ point deficit) even if they had no other sources of lead exposure. However, even more recently, in what is probably the most precise study of IQ deficits from very low-lead exposure, Canfield *et al.* (2003) found that six-year-olds with BLLs of just 10 ug/dL on average scored 7.4 IQ points lower than a control group of six-year-olds with BLLs of less than 1.0 ug/dL. They conclude from their study that small lead exposures cause most of the neurologic damage and that additional exposure causes only slight additional damage. Their results would indicate that a 3.2 ug/dL BLL increase as calculated above for water ingestion of 2.0 liters/day of 10 ug/L lead concentration would result in an approximate 2.6 point IQ deficit as opposed to the 1.3 IQ point deficit extrapolated from earlier, less sensitive studies.

It has been estimated that 14 to 20 percent of total US childhood lead exposure is from drinking water, although of course, essentially all lead exposure for a particular child could easily come from tapwater in any particular residence (US EPA, 1991). Also, the recent work of Canfield *et al.* (2003) strongly suggests that this 14 to 20 percent exposure from drinking water, because it is spread over millions of children, may actually be responsible for a much higher percentage of the total neurologic damage caused by lead exposure in the US.

B. Chronology of Reduction of Lead in Drinking Water in the United States

July 1988: Federal Lead Ban Enforcement Deadline: Leaded-solder eliminated in new buildings. (However, pre-1988 buildings will continue to have leaded solder for decades to come).

December 1994: Use of leaded brass in submersible well pumps banned nationally by the US EPA.

June 1998: Kitchen and lavatory faucets: California Proposition 65 settlement agreement requires that residential faucet fixtures meet a very low lead discharge standard (achievable only with no-lead or very low lead alloys). Standard was adopted nationally by most faucet companies.

March 2000: CA Prop 65 settlement agreement to eliminate the use of leaded-brass alloys in residential water meters. Specifies Federalloy or Sebiloy (aka EnviroBrass) alloys. (Now available nationally from Schlumberger and others.)

2001-present: CA Prop 65 litigation at an advanced stage which would require no-lead or very low lead alloys in residential gate valves, ball valves, backflow preventers, and pressure reducing valves.

2002: Virtually all leaded brass plumbing components have now been (or are close to being) banned from use in residential and most other building plumbing systems, at least in California. Only leaded-brass water service parts such as curb valves, meter stops, tailpieces, elbows and main (corporation) stops have not yet been addressed.

October 10, 2002: A 60-day CA Prop 65 notice was filed with the appropriate CA Public enforcement agencies against Mueller, A.Y. McDonald, Ford Meter Box, and James Jones for illegally manufacturing and selling leaded-brass water service components in the State of California. This case is still under litigation and settlement discussions in California.

Nationally, many brass plumbing and most water service parts are still being made from leaded brass alloys containing between about 2 and 7 percent lead. It is now well documented that these leaded brass parts discharge substantial amounts of lead into residential drinking water, especially when new, but even after years of in-line service. A large comprehensive study by Lytle and Schock, (1996), with the US EPA, found that virtually all such leaded alloys leached and discharged substantial concentrations of lead for extended periods. A series of experiments conducted by the UNC-Asheville Environmental Quality Institute (EQI) on water meters and valves documented that new leaded brass parts typically leach about 100 ug/L of lead initially, with the levels typically decreasing to about one-half of initial values within weeks, followed by a long-term stabilization at moderate lead discharge levels (20-30 ug/L), depending on supply water corrosivity, after about five months of service (Maas and Patch, 1999; Maas *et al.,* 1997; Maas *et al*, 1999).

Another recent study by the EQI found that leaded brass curb valves and water meters in the Los Angeles public water system were still discharging high amounts of lead after two or more years of service. These discharges were calculated to be sufficient to cause significant exposures, measurable increases in blood lead levels, and IQ deficits among Los Angeles children (Maas, 2001; Maas, 2002). Based on these findings, the City of Los Angeles Department of Water and Power is now only purchasing no-lead parts for their water distribution and delivery system.

This most recent California Proposition 65 legal action raises a new set of issues for public water suppliers. Nearly all previous regulations and legal actions concerning the elimination of lead-containing plumbing components from the water system have focused on parts at least ostensibly under the jurisdiction and control of the homeowner, while this latest concern relates to leaded brass parts owned by the public water supplier which are installed and replaced without the knowledge of sanction or the homeowner. That water service parts under the perview of public water suppliers would be among the last leaded-brass parts to still be installed in residential water supply systems seems particularly ironic given that for the past eleven years public water suppliers nationwide, through the Federal Lead and Copper Rule, have led the way in reducing the exposure of the US public to lead in drinking water by spending hundreds of millions of dollars on lead corrosion optimization, increasing public awareness, and other measures.

Thus, it was the purpose of these experiments and this paper to attempt to quantify the actual public lead exposure and public health implications represented by the use of leaded versus lead-free brass water service parts and water meters and to discuss some of the scientific, legal, and ethical issues raised by the current actions to eliminate these final sources of lead in new residential water supply connections.

II. METHODOLOGY

There are currently several major suppliers of water service parts in North America, and this project attempted to identify and test a broad spectrum of parts produced by each of leading manufacturers. Cambridge Brass, and to a lesser extent, James Jones currently appear to be the only two of the companies producing a relatively complete line of "No-Lead" brass water service parts (<0.1% Pb), although others such as A.Y. McDonald will reportably also have no-lead water service parts available within the next year. Neptune sells only “no-lead” type water meters in North America. At the time this research project was initiated, only Cambridge Brass was manufacturing and selling a relatively complete line of “no-lead” water service parts, and thus, these were used for comparison with equivalent traditional leaded-brass alloy parts. A complete list of the products tested by this research is shown and described in Table 1 below:

TABLE I. Description of Plumbing Products to be Tested for Lead Discharge Dynamics.

Lab Set ID #	Manufacturer	Manufacturer ID #	Description	Sample Size	Notes
1	Camb. Brass	202NL-F3F3	3/4" Ball Valve Curb Stop FIP x FIP	250 ml	
2	Camb. Brass	203NL-F3F3	3/4" Ball Valve Curb Stop with Drain FIP x FIP	250 ml	
3	Camb. Brass	212NL-F3F3	3/4" Full Port Straight meter Stop FIP x FIP	250 ml	
4	Camb. Brass	262NL-F3F3	3/4" Minneapolis-style Ball Valve Curb Stop FIP x FIP	250 ml	
5	Camb. Brass	301NL-M3M3	3/4" Ball-type Main Stop MIP x MIP	250 ml	
6	Camb. Brass	210 NL-F4F4	1" Full Port Angle Meter Stop FIP x FIP	250 ml	
7	Camb. Brass	117NL-H3F3	3/4" Straight Coupling Comp x FIP	250 ml	
8	Camb. Brass	105NL-H3M3	3/4" Ell Coupling Cambridge Comp x MIP	250 ml	
9	Camb. Brass	150NL-H3H3	3/4" Service Tee Comp x Comp x Comp	250 ml	
10	Camb. Brass	202HL-H3H3	3/4" Ball Valve Curb Stop Comp x Comp	250 ml	
11	Camb. Brass	6020NL-207H3F3-00	3/4" Meter Setter	Dump & fill	
12	Camb. Brass	202NL-F7F7H	2" Ball Valve Curb Stop	one liter	
13	Mueller	B-20283	3/4" FIP x FIP B/V Curb Stop	250 ml	
14	Mueller	H-15531	3/4" Comp x MIP Elbow CPLG	250 ml	
15	Mueller	H-15071	3/4" Comp x MIP Elbow CPLG	250 ml	
16	Mueller	B-20283	2" FIP x FIP B/V w/Handle	one liter	
17	James Jones	J-1943	3/4" MIP x MIP Main Stop	250 ml	
18	James Jones	J-1900	3/4" FIP x FIP F/Port Straight	250 ml	tested 4
19	James Jones	J-2619	3/4" Comp x MIP Elbow CPLG	250 ml	
20	James Jones	J-2607	3/4" Comp x FIP CPLG	250 ml	
21	James Jones	J-1900	2" FIP x FIP B/V w/Handle	one liter	
22	A McDonald	3131B	3/4" MIP x MIP Main Stop	250 ml	
23	A McDonald	6101	3/4" FIP x FIP B/V Curb Stop	250 ml	
24	A McDonald	6101W	3/4" FIP x FIP F/Port Straight MTR w/Lockwing	250 ml	tested 2
25	A McDonald	4779M-22	3/4" Comp x MIP Elbow CPLG	250 ml	
26	A McDonald	4754-22	3/4" Comp x FIP CPLG	250 ml	

27	A McDonald	6101ADD6120	2" FIP x FIP B/V w/Handle	one liter	
28	Ford	B11-333W	3/4" FIP x FIP F/PORT Straight MTR w/Lockwing	250 ml	
29	Ford	L84-33	3/4" Comp x MIP Elbow CPLG	250 ml	tested 4
30	Ford	C14-33	3/4" Comp x FIP CPLG	250 ml	
31	Ford	T444-333	3/4" x 3/4" Comp Tee	250 ml	
32	Ford	B11-777	2" FIP x FIP B/V w/Handle	one liter	
33	James Jones	J-1900	3/4" FIP x FIP B/V Curb Stop	250 ml	
34	James Jones	J-1949	3/4" Comp x Comp B/V Curb Stop	250 ml	
35	James Jones	J-2617	3/4" x 3/4" Comp Tee	250 ml	
36	Mueller	H-15381	3/4" x 3/4" Comp Tee	250 ml	
37	Mueller	B-24265	1" FIP x Meter Nut F/Port Angle Meter Valve	Dump & fill	
38	Mueller	B-20200	3/4" FIP x FIP F/Port Straight MTR w/Lockwing	250 ml	
39	A McDonald	4760-22	3/4" x 3/4" Comp Tee	250 ml	
40	Mueller	B-20013	3/4" MIP x MIP Main Stop	250 ml	
41	Ford	BA13-444W	1" FIP x Meter Nut F/Port Angle Meter Valve	Dump & fill	
42	Ford	B11-333	3/4" FIP x FIP B/V Curb Stop	250 ml	
43	Ford	FB500-3	3/4" MIP x MIP Main Stop	250 ml	
44	Mueller	B25170	3/4" FIP x Comp B/V Curb Stop	250 ml	
45	Ford	B44-333	3/4" FIP x Comp B/V Curb Stop	250 ml	
46	A McDonald		1" FIP x Meter Nut F/Port Angle Meter Valve	Dump & fill	
47	A McDonald	6100-22	3/4" Comp x Comp B/V Curb Stop	250 ml	

After thorough rinsing and pre-conditioning as specified by NSF-61 Section 9 (NSF, 2001), the individual components (141 total) were plumbed with PVC or polybutylene connectors or adapters to the EQI lead-free research pressurized manifold system. An extraction water was prepared that closely simulates average California public water supply characteristics in terms of lead corrosivity (Maas and LaGoy, 1999). This water had an average pH of 8.04 (+ or - 0.3), mean hardness of 100 mg/L (as $CaCO_3$), mean alkalinity of 82.4 mg/L (as $CaCO_3$)(+ or - 5 mg/L) and total chlorine of 1.0 mg/L. Using laboratory pumps and timers, this extraction water was fed to the test parts with five water changes per day. Sixteen hour internal dwell water from the brass products was sampled on Days 3, 4, 5, 10, 11, 12, 17, 18, and 19. On Days 17, 18 and 19, shorter dwell time samples were also taken after 10 minutes, 30 minutes, and 2 hours. This short dwell time data enabled a calculation of the approximate total daily lead discharge from the parts and as well as the approximate ingestion by residence occupants. The lead discharge concentration data were statistically analyzed to determine a lead discharge “Q”statistic as defined for certification purposes by NSF (NSF, 2001). Thus, the experimental procedures used were virtually identical to NSF-61 Section 9 with the exceptions that 1) the parts were plumbed rather than just 'dumped and filled', 2) water hardness, alkalinity and total chlorine levels used were more representative of typical California public water supplies than the levels specified under NSF, and 3) short dwell time samples were taken in addition to 16-hr. overnight dwell samples.

All samples were analyzed for total lead by graphite furnace atomic absorption spectrophotometry (GFAAS) with a research method detection limit of approximately 0.5 ug/L. Instrument readings of less than 0.5 ug/L were reported and were used for statistical analyses to avoid the problems associated with truncated data sets.

III. RESULTS AND DISCUSSION

Lead discharge results are summarized in Table 2. As expected, the lead discharges from the "no-lead" water service parts (#s 1-12) were relatively low.

TABLE 2. Summary of 16-hour Dwell Lead Discharges (ug/L)(250-mL samples).

Product ID#	Mean Internal Exposed Volume (mL)	Mean Lead Days 2-5	Mean Lead Days 9-12	Mean Lead Days 16-19	Overall Mean	1-L Adjusted Overall Mean	'Q' Stat
1	13.1	3.86	1.96	2.51	2.78	0.70	0.91
2	13.0	3.98	1.58	2.08	2.55	0.64	0.60
3	14.5	3.01	1.54	1.54	2.03	0.51	0.53
4	17.3	4.51	2.11	2.86	3.16	0.79	0.78
5	29.4	10.0	5.39	5.55	6.98	1.75	2.81
6	21.6	10.6	5.65	5.01	7.09	1.77	2.23
7	18.0	4.34	1.97	1.36	2.56	0.64	1.79
8	32.0	8.92	5.33	4.88	6.38	1.60	2.64
9	51.0	9.29	5.74	3.83	6.29	1.57	1.64
10	32.0	9.16	4.01	2.29	5.15	1.29	1.31

11*	159.	24.1	9.39	6.43	13.3	3.33	3.56
12**	185.	6.04	3.88	2.76	4.23	4.23	5.48
13	12.5	40.4	25.1	25.0	30.2	7.55	13.75
14	21	39.4	60.2	43.1	47.6	11.9	17.90
15	6.5	21.4	17.4	21.0	19.9	4.98	8.89
16	155	38.4	24.0	21.6	27.8	27.8	48.30
17	35	44.5	45.2	29.3	39.6	9.9	13.93
18	15	46.0	27.6	28.4	34.0	8.5	14.36
19	23	74.5	40.9	36.3	50.6	12.65	13.92
20	11	29.7	17.9	22.1	23.2	5.8	6.90
21	160	67.9	41.9	39.6	49.8	49.8	54.32
22	35	82.6	48.9	44.9	58.8	14.7	19.67
23	14	35.3	20.1	20.4	25.3	6.33	8.18
24	14	15.8	20.1	21.4	19.1	4.78	5.09
25	26	35.6	21.1	22.3	26.3	6.59	22.4
26	8	11.1	9.1	7.1	9.1	2.28	2.27
27	160	64.3	44.0	42.1	50.1	50.1	51.96
28	15.5	40.2	28.6	28.1	32.2	8.05	8.48
29	18	47.8	20.1	20.9	29.6	7.4	11.86
30	10	9.47	8.36	3.28	7.0	1.75	5.53
31	15	71.4	53.1	43.1	56.3	14.1	13.72
32	160	64.0	47.1	41.0	50.7	50.7	72.20
33	18	25.3	27.4	21.6	24.7	6.18	11.07
34	35	74.1	56.5	38.7	56.4	14.1	40.59
35	55	48.0	36.6	34.8	39.8	9.94	17.31
36	55	59.3	42.1	36.5	46.0	11.5	12.91
37	45	18.07	349.1	269.7	808.6	202.2	298.5

38	15	65.7	26.0	22.0	37.9	9.47	7.30
39	20	111.4	164.8	130.2	135.5	33.9	147.2
40	31	97.1	56.6	46.3	66.7	16.7	23.88
41	50	321.7	241.2	250.7	271.2	67.8	70.20
42	21	40.3	33.6	28.5	34.1	8.53	12.57
43	30	63.4	48.5	45.6	52.5	13.1	13.87
44	22	39.4	82.6	62.5	61.5	15.4	63.36
45	17	32.6	39.0	26.7	32.8	8.19	15.31
46	60	679.1	240.7	256.1	392.0	98.0	101.46
47	32	46.9	33.4	31.5	37.3	9.32	12.48

* Due to plumbing difficulties, CB11 was conditioned and tested using a ‘Dump & Fill’ protocol with water change and sampling procedures identical to plumbed pieces.

**One-liter samples taken because of large volume of part.

Lead discharge concentrations of the “no-lead” parts shown in Table 2 decreased significantly over the three weeks of testing with Week 3 results giving a mean Pb concentration of 42 percent of Week 1 results. In contrast, on Week 3 the leaded brass parts were still discharging 71 percent of the lead they discharged during Week 1 of testing. Thus, the rate of decrease was significantly less for the leaded brass parts over the three weeks of testing, perhaps because of the much larger amounts of surface lead initially available for dissolution.

Table 3 shows comparisons between the “no-lead” type water service parts and their approximate counterparts manufactured from conventional leaded brass.

TABLE 3. Comparison of Lead Discharge (ug/L) From “No-Lead” Parts Versus Similar Leaded Brass Parts.

No-Lead Part ID #	Comparable Leaded Brass ID #s	‘Q’ Stat for No-Lead Part	Mean ‘Q’ Stat for Leaded Brass Parts	Factor Difference in Lead Discharge
1	13, 23, 33, 42, 44, 45	0.91	20.7	22.8
2	13, 23, 33, 42, 44, 45	0.60	20.7	34.5
3	18, 24, 28, 38	0.53	8.81	16.6

4	13, 23, 33, 42, 44, 45	0.78	20.7	26.5
5	17, 22, 40, 43	2.81	17.8	6.35
7	15, 20, 26, 30	1.79	5.90	3.30
8	14, 19, 25, 29	2.64	16.5	6.25
9	31, 35, 36, 39	1.64	47.8	29.1
10	34, 44, 45, 47	1.31	32.9	25.1
12	16, 21, 27, 32	5.48	56.70	10.3
Mean				18.0

From Table 3 it can be seen that, as expected, the "no-lead" parts discharged much less lead than their conventional leaded brass equivalents under these test conditions. Depending on the part, the "no-lead" parts discharged anywhere between 3.30 and 34.5 times less lead with an average of 18.0 times less lead discharged.

Given that the lead content of the "no-lead" type water service fittings (mean = 0.07 percent; max = 0.1 percent) is so much lower than the corresponding conventional leaded brass fitting (which are generally manufactured from brass alloys containing either 5 percent or 7 percent lead), it might be expected that the difference in lead discharge would be significantly greater than the average factor of 18.0 which was observed. However, it has been previously noted by various researchers that, when brass alloys are melted and poured into molds, the lead (having a lower melting point and thus becoming less viscous in the alloy suspension) tends to migrate and concentrate at the interface of the mold, generally producing surface concentrations of about two to four times that of the bulk alloy. An examination of the data indicates that this is quite likely the case given that the lead discharge of the "no-lead" parts decreased by 58 percent from Week 1 versus Week 3, while the conventional leaded brass parts showed average decreases of only 28.5 percent. Over time, as the relatively small amount of initially accumulated surface lead dissolves out of the "no-lead" parts, this difference would be expected to become even greater, presumably stabilizing eventually at the approximate 50-fold difference represented by the respective lead content of the "no-lead" versus a typical 5 percent leaded-brass alloys.

On Days 17, 18 and 19 of these experiments samples were taken after relatively short internal dwell times of 10 minutes, 30 minutes and 2 hours. This short dwell time discharge data enables more accurate estimations to be make of total lead discharge from plumbing systems and subsequent ingestion because in most cases, residents will be consuming water with much less than an overnight dwell time. Across all parts it was found that on average 58 percent of the 16-hour dwell time lead concentrations was discharged after a 2-hour dwell time, with 31 percent and 19 percent of the 16-hour dwell concentrations discharged after 30 minutes and 10 minutes, respectively. These results are consistent with several previous studies (Maas and Patch, 1999; Maas *et al.,* 1997; Maas *et al.,* 1999), and illustrate clearly the non-linearity in the kinetics of lead dissolution from plumbing systems.

IV. APPROXIMATE CALCULATIONS AND ESTIMATIONS OF LEAD EXPOSURE FROM WATER SERVICE PARTS

There are a number of methods for calculating and estimating the lead discharge and ingestion exposure from the installation of brass water service parts, and several of these have been previously described in some detail (e.g., Maas *et al.,* 1999; Maas, 2001; Maas, 2002). By necessity, any such calculations can only be approximate since water corrosivity varies considerably between public systems and households and individual water usage patterns will vary significantly from residence to residence. The lead discharge data developed from the current experiments was utilized to develop reasonable estimates of lead discharge and human consumption for an entire typical system of water service components as well as for each individual component as shown below. The following parameters, approximations, and assumptions were employed.

1. In a typical residence with four occupants, the water would be used on average about 30 times/day for drinking, cooking, washing, showers, and toilet-flushing, etc., with these uses apportioned as: one overnight dwell, four 2-hour dwells, 15 30-minute dwells, and 10 10-minute dwells.

2. On average, each resident would consume 2.0 liters/day of water total for drinking and cooking.

3. Water ingestion would be apportioned as eight 250-ml faucet draws/day for each occupant with about an equal chance of receiving a dwell slug of 10-min., 30-min., 2-hr., and overnight (in reality, ingesting part of the overnight dwell slug would be less likely, but consuming parts of dwell

slugs of greater than 2-hour dwell times or 30-minute dwell times is more likely).

4. The 250-ml sample taken from the laboratory plumbing set-up represents approximately the dispersion, which would occur between the water part and the tap.

5. The average home has about 4.5 liters of water storage in the plumbing system (i.e., 80 ft. of one-half inch interior plumbing plus 20 ft. of three-fourths inch service line). Thus, combined with #4, there is about a 1/18 (i.e., 0.25 L divided by 4.5 L) chance of getting the dwell slug from any given water service part in any particular 250 ml tap-water draw.

6. The residence is served by the average California public supply water used in these experiments.

7. The typical residential system contains a main stop, elbow straight coupling, curb stop, main stop tail pieces, a water meter and water meter tail pieces.

A. Total Daily Lead Discharge

A typical residential plumbing system with “no-lead” water service parts installed would include Part #s 5, 7, 8, and 10 from Table 1, plus a lead-free water meter and tail pieces. From Table 2, employing the assumptions 1-7 noted above, such a system would discharge a total of about 50 ug of Pb per day (28 ug from part #s 5, 6, 8, and 10 plus 22 ug from the water meter and tail pieces). One typical combination of parts for a residence with conventional leaded brass service parts would include part #s 17, 25, 29, and 47 from Table 1, plus a leaded-brass water meter and tail pieces. From Table 2 and assumptions 1-7 above, this system would discharge approximately 332 ug/day of lead (205 ug from part #s 17, 25, 29 and 47 plus 127 ug from the water meter and tail pieces).

B. Calculated Daily Lead Ingestion

As noted above, the lead ingestion calculations assume that there is about a 1/18 probability of ingesting a water service part 250-ml dwell slug with each of the eight faucet draws per day. Under the assumption that ingesting a dwell-slug of each of the experimental dwell times to be about equally likely, the daily Pb ingestion from each part can be calculated as follows:

Ingestion (ug/day) = Mean of Pb conc. of all four dwell times (ug/L) x 0.25 L/draw x 8 draws/day x 1/18 probability of ingesting a dwell slug per draw

This Pb ingestion estimation is calculated for each individual water service part in Table 4 below.

TABLE 4. Calculated Daily Lead Ingestion for Various Brass Water Service Parts.

Lab ID# of Part	Calculated Daily Lead Ingestion (ug)	Lab ID# of Part	Calculated Daily Lead Ingestion (ug)
1	0.12	25	1.11
2	0.10	26	0.32
3	0.08	27	2.16
4	0.12	28	1.54
5	0.24	29	1.02
6	0.26	30	0.16
7	0.08	31	2.48
8	0.21	32	1.92
9	0.20	33	0.92
10	0.11	34	2.18
11	0.40	35	2.38
12	0.10	36	1.82
13	1.19	37	17.21
14	2.30	38	1.82
15	1.13	39	8.10
16	0.95	40	2.18
17	1.49	41	13.96
18	1.43	42	1.43
19	1.79	43	2.23

20	1.19	44	4.63
21	1.82	45	1.47
22	2.15	46	13.18
23	0.95	47	1.58
24	0.82		

The ingestion estimates shown in Table 4 are derived from the lead discharge data from Days 17-19 of these experiments. During the first few days of service, new water service parts could be expected to discharge (with resulting ingestion) considerably more lead than observed on Days 17-19, while at later service ages the expected discharge and ingestion exposure would be somewhat less. Previous experiments conducted by the EQI have demonstrated, however, that after Day 19, further discharge reductions are relatively minimal (Maas, *et al.,* 1997; Maas and Patch, 1999). California's Proposition 65 sets daily exposure limits for consumer products and water discharges at 0.5 ug/day, and it can be seen from Table 4 that nearly all of the leaded brass parts result in calculated exposures which significantly exceed this level. As noted previously, exposure calculations were made assuming an approximately equal likelihood of consuming a dwell slug of 10-minutes, 30-minutes, 2-hours, and overnight. Although in reality, consumption of the overnight dwell slug is somewhat less likely, it is highly probable that a large majority of the ingested slugs would have dwell times greater than 10 minutes or 30 minutes. Also, because the kinetics of lead build-up in the water is very non-linear (i.e., a substantial percentage of the overnight dwell slug concentrations builds up just in the first 10 to 30 minutes), the Pb ingestion calculations are relatively insensitive to the assumptions made regarding the distribution of dwell slugs ingested. For instance, if it is assumed that the overnight dwell slug is almost never consumed, but that consumption of a 2-hour or 30-minute dwell slug is twice as likely as consuming a 10-minute dwell slug, the calculated daily ingestion is nearly the same.

The data from Table 4 can be used to estimate the total daily lead ingestion of building occupants. Combining these daily ingestion calculations with the US EPA's and FDA's analysis that each ug/day of ingestion will raise a young child's blood lead level (BLL) by 0.16 ug/dL (FDA, 1993) and that each 10 ug/dL BLL increase will cause a 7.4 point IQ deficit (Canfield, *et al.,* 2003), enables a reasonable estimate of BLL increases and IQ deficits to be calculated as summarized in Table 5.

TABLE 5. Total Calculated Daily Pb Exposures, Childhood Blood Lead Level Increases, and IQ Deficits.

Water Delivery System Type	***Total Daily Lead Ingestion (ug)***		***BLL ug/dL***		***IQ Deficit***	
	mean	90th%	mean	90th%	mean	90th%
"No-Lead"	1.15	1.86	0.18	0.30	0.12	0.21
Conventional leaded-brass	5.20	9.50	0.83	1.52	0.58	1.07
Conventional leaded-brass in most corrosive 20% of CA system (approx. pop. = 5 million)*	12.5	22.8	2.00	3.65	1.40	2.56

*From results for Los Angeles curb valves and water meters (16) and study of CA public water supply corrosivity (21).

From Table 5 it can be seen that the impact on BLLs and IQ range from virtually negligible for the system with "no-lead" type water service parts, to significant and measurable impacts for the most exposed 10 percent of children in California towns and cities with more corrosive water (estimated 250,000 children). Average California public water supplies appear to be about equivalent to United States averages (Maas and LaGoy, 1999), but New England public water supplies would tend to be even more corrosive than the test waters used in these experiments, thus leading to even higher risk estimates.

V. SUMMARY AND CONCLUSIONS

We are now aware that even very low lead exposures cause neurologic damage, especially in infants and young children resulting in IQ reductions, attention deficit disorders, aggressive behavior and reading disabilities.

Leaded-brass water service parts represent a small to moderate additional source of lead exposure to infants and young children, leading to easily measurable BLL increases and IQ deficits of about 0.58 to 2.56 points, along with other lead-related neurological problems. The effects could be even greater for many New England public water supplies with more corrosive water.

Some infants and young children, due to unfortunate water consumption habits, will receive lead exposure from drinking water much higher than those estimated from this study.

While the increase in childhood lead exposure from leaded-brass water service parts is usually relatively small, this is a needless extra exposure with the effects additive to other lead exposures.

We are rapidly getting closer to eliminating leaded parts from our drinking water systems, and with the pending current Prop 65 litigations it will probably soon be illegal to manufacture and sell leaded-brass water system parts of any type in California.

The cities of Los Angeles, Detroit, Tampa, Bangor, Portland and many other towns nationwide are already purchasing only "no-lead" water service components.

VI. SOME FINAL THOUGHTS AND QUESTIONS

1. Given our recent knowledge about health effects of lead, and considering that leaded-brass water service parts installed today will be in service discharging lead for the next 20 to 40 years, perhaps it is time for all public water suppliers to proactively eliminate this unnecessary source of lead to our customers by specifying only "no-lead" water service brass and water meters.

2. When the next wave of media publicity about the irreversible health effects of low level lead exposure comes to public attention, how will we explain to our customers why we are still installing leaded-brass parts in 2003 given that lead-free parts have become readily available?

3. Class Action Suits and Personal Injury Suits have gotten completely out of control in the US (78 percent of our Congress are attorneys!). If public water suppliers are shown to have been still installing leaded-brass parts even after virtually all of the parts in residences were converted to "no-lead" brass, could we be vulnerable to these types of legal actions?

4. Currently "no-lead" water service parts cost about 25 percent more than conventional leaded-brass parts due to the higher ingot cost. However, for a city with 1 percent annual service replacements and 1 percent growth in new service installations, the extra cost spread across the customer base comes out to be about 4¢/month per household.

5. Parts that simply comply with NSF-61 Section 8 do not provide adequate protection from lead exposure given what is now known about the effects of even very low exposures to children. A part with a 100 mL internal volume could discharge up to 450 ug/L of lead and still receive the NSF-61 Section 8 certification!

6. We as public water suppliers have led the way in reducing lead in drinking water. We now have an opportunity to finish our part of the job once and for all!

VII. REFERENCES

American Water Works Association. 1990. Water Quality and Treatment (4th Edition). New York: McGraw Hill Publishing.

ANSI/NSF. 2001. *Section 9, Testing of Drinking Water Components.* Available from NSF, Ann Arbor, MI.

Bellinger, D., A. Leviton, C. Wateraux, H. Needleman and M. Rubinowitz. 1987. *Longitudinal Analysis of Cognitive Development.* New England Journal of Medicine, 316:1037-1043.

Bois, E.Y. *et al.* 1989. *Application of Clearance Concepts to the Assessment of Exposure to Lead in Drinking Water.* American Journal of Public Health, 79(7):827-831.

Canfield, R.L., C.R. Henderson, D.A. Cory-Slechta, C. Cox, T.A. Susko and B.P. Lanphear. 2003. *Intellectual Impairment in Children With Blood Lead Concentrations Below 10 ug per Deciliter.* New England Journal of Medicine, 348(16):1517-1526.

Lanphear, B. 2001. *Cognitive Deficits Associated With Blood Lead Concentrations < 10 ug/L in US Children and Adolescents.* Public Health Reports.

Lappman, M. 2000. Environmental Toxicants: Human Exposures and Their Health Effects. New York: John Wiley and Sons.

Lytle, D.A. and M.R. Schock. 1996. *Stagnation Time, Composition, pH and Orthophosphate Effects on Metal Leaching From Brass* (EPA/600/R-96-103). September 1996.

Maas, R.P. 2001. *Estimation of Human Lead Exposure From In-Spec (<6% Pb) and Out-of-Spec (>6% Pb) Leaded Brass Curb Valves, Curb Valve Tail Pieces, Elbow Connector Nuts, Corporation Nuts and Corporation Threads*. UNC-Asheville Environmental Quality Institute Technical Report, April 30, 2001. 8p.

Maas, R.P. 2002. *Estimation of Human Lead Exposure from Leaded Brass Water Works Parts Installed in Residential Service.* UNC-Asheville Environmental Quality Institute Technical Report, April 2002. 9p.

Maas, R.P. and M.S. LaGoy. 1999. *Survey of Average California Public Water Supply Corrosivity Characteristics.* UNC-Asheville Environmental Quality Institute.

Maas, R.P. and S.C. Patch. 1999. *Lead Leaching From In-Service Residential Water Meters: A Laboratory Study.* Source (CA Section of AWWA), 100(3):27-28.

Maas, R.P., S.C. Patch, D.M. Morgan and H. Kawaguchi. 1997. *Lead Leaching From Brass Water Meters Under Pressurized Flow Conditions.* Proceedings of the American Water Works Association 1997 Annual Conference, 589-602.

Maas, R.P., S.C. Patch, D.M. Morgan and S.C. Loucaides. 1999. *Lead Leaching From Los Angeles In-Service Brass Water Meters.* UNC Asheville Environmental Quality Institute Technical Report #99-068. 17p.

McMichael, A.J. *et al.* 1988. *Port Pirie Cohort Study: Environmental Exposure to Lead and Children's Abilities at the Age of Four Years.* New England Journal of Medical, 319:468-475.

Needleman, H.L. and C.A. Gatsonis. 1990. *Low-Level Lead Exposure and the IQ of Children: A Meta-Analysis of Modern Studies.* Journal of the American Medical Association, 263(5):673-678.

Needleman, H.L. *et al.* 1990. *The Long-Term Effects of Exposure to Low Doses of Lead in Childhood: An 11-Year Follow-up Report.* New England Journal of Medicine*, 322:83-88.*

Schwartz, J. 1994. *Low-Level Lead Exposure and Children's IQ: A Meta-Analysis and Search for a Threshold.* Environmental Research, 65:42-55.

Sciorello, W.G., G. Alexander and K.P. Farrell. 1992. *Lead Exposure and Child Behavior.* American Journal of Public Health, 82:1356-1360.

U.S. Department of Health and Human Services. Food and Drug Administration, Part II. 58 Federal Register 117 (June 1, 1993), codified at 21 CRF parts 109 and 189.

U.S. Environmental Protection Agency. February 1995. *Lead Poisoning and Young Children* (EPA 800-B-92-0002). Washington, DC.

U.S. Environmental Protection Agency. Drinking Water Regulations: Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Copper. 53 Federal Register 110 (June 7, 1991).

Richard Maas and Steven Patch are Co-Directors of the UNC-Asheville Environmental Quality Institute, a nationally known research institute focusing on water supply research. Dr. Maas has long served on the Board of Directors of his local public water supply utility, the Regional Water Authority of Asheville-Buncombe and Henderson, which supplies 25 MGD to a two-county area.