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## Mercury vapor in residential building common areas in communities where mercury is used for cultural purposes versus a reference community

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### ABSTRACT

**Background:** Exposure to elemental mercury ( $\text{Hg}^0$ ) in residential buildings can occur from accidental spills, broken objects (thermometers, fluorescent fixtures, thermostats), and deliberate introduction, one mode of which involves cultural practices by individuals who believe dispersal of mercury in a residence will bring luck, enhance health or ward off harm. **Objectives:** To determine whether mercury vapor levels in common areas of residential buildings is higher in a community where cultural uses are likely (study areas S1, S2) than in a reference community (C1) where cultural use is unlikely, and whether levels can serve as a signal of significant cultural mercury use.

**Methods:** We monitored  $\text{Hg}^0$  vapor with a portable spectrophotometer in the three communities. We randomly selected sites in S1 and C1 community, and also include sites in S2 specified by local health officials who suspected cultural mercury use. We evaluated 122 multifamily buildings and 116 outdoor locations.

**Findings:** We found  $>25 \text{ ng/m}^3 \text{ Hg}^0$  in 14% of buildings in study areas compared to only one reference building. In the latter we identified an accidental mercury spill from a bottle that had been brought into the building. Both the mean and maximum indoor mercury vapor levels were greater in the study communities than in the reference community. In all communities, we observed mean indoor  $\text{Hg}^0$  vapor concentration greater than outdoors, although in two-thirds of buildings, indoor levels did not exceed the area-specific outdoor upper-limit concentration.

**Conclusion:** After controlling for factors that might influence  $\text{Hg}^0$  vapor levels, the most plausible explanation for greater  $\text{Hg}^0$  levels in the study area is a relationship to cultural use of mercury. None of the measured levels exceeded the ATSDR minimum risk level for residences of  $200 \text{ ng/m}^3 \text{ Hg}^0$  although levels in living quarters might be greater than those in the common areas.

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Abbreviations: C, centigrade; ca., circa; CI, confidence interval;  $\text{cm}^2$ , square centimeter;  $\text{Hg}^0$ , elemental mercury; km, kilometer;  $\text{m}^3$ , cubic meter; mg, milligram; n, number; ng, nanogram; SD, standard deviation;  $\mu\text{g}$ , microgram.

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## 1. Introduction

Elemental mercury ( $\text{Hg}^0$ ) is unique among the elements due to its physical attributes as well as the magical and spiritual attributes that humankind has bestowed upon it for millennia. South Asian and Chinese cultures viewed  $\text{Hg}^0$  with reverence for thousands of years and it was essential to the alchemists. Today, icons formed with *parad*, a mercury amalgam, are available and said to bestow peace and prosperity (Astrohastra, 2007).

$\text{Hg}^0$  use in the United States (U.S.) is associated with Afro-Caribbean traditions such as Palo Mayumbe, Santeria, and Voodoo as well as with certain cultural uses (e.g., sprinkling mercury in cars, candles or cradles has been reported (Johnson, 1999; Johnson, 2004; Ozuah et al., 2003; Riley et al., 2001, 2006; Stern et al., 2003; U.S. EPA, 2002; Wendroff, 1990; Zayas and Ozuah, 1996). In urban areas with a Caribbean population, mercury is widely available in stores called “botanicas”. In the Dominican Republic we purchased several grams of  $\text{Hg}^0$  in a botanica and were instructed to spread mercury on the floor within the home and the most auspicious days to do so. Wendroff (2005) and Quintero-Somains and Quirindongo (2004) contend mercury contamination of homes may be widespread in communities where  $\text{Hg}^0$  is used in religious or cultural practices. However, we believe it is important to differentiate  $\text{Hg}^0$  use during ceremonies or the formal practices conducted by initiates, santeros, or priests with those of “laypersons” who may disperse  $\text{Hg}^0$ .

Trained practitioners report ceremonial practices do not involve dispersal of mercury but others may use it in accordance with folk traditions or more casual practices that involve dispersal of mercury within a residence (Lythcott, 2003; Riley et al., 2006; Riley et al., 2001; Stern et al., 2003; U.S. EPA, 2002). Practitioners within the Afro-Caribbean traditions have a vested interest in retaining control of rituals, recognize the hazards of mercury, do not condone its use by “laypersons”, and in some cases have initiated actions within their community to curtail inappropriate  $\text{Hg}^0$  use (Lythcott, 2003; Riley et al., 2006).

To date, the extent of cultural mercury use has been indirectly assessed by interview and assessment of the availability of mercury in botanicas (Johnson, 1999, 2004; Ozuah et al., 2003; Riley et al., 2001; Stern et al., 2003; U.S. EPA, 2002; Wendroff, 1990; Zayas and Ozuah, 1996). Cultural use of mercury may present an insidious source of exposure in households. A recent survey in New England found a large number of individuals knowledgeable of  $\text{Hg}^0$  uses in the home, including sprinkling  $\text{Hg}^0$  in a child’s bed or infant’s crib (JSI Center for Environmental Studies, 2003). In Washington D.C., officials conducting screenings of individuals exposed to  $\text{Hg}^0$  from a spill in a school laboratory found the highest blood mercury levels in individuals who also used it culturally (Goldstein, 2003).

Although the magnitude of exposure to  $\text{Hg}^0$  vapor from cultural use is unknown, the hazard of  $\text{Hg}^0$  vapor is well established.  $\text{Hg}^0$  released in a home could present a persistent hazard. Mercury vapor is detectable years after small spills as from a broken fever thermometer (Carpi and Chen, 2001; von Muhlen Dahl, 1990). With larger spills, significant concentrations of  $\text{Hg}^0$  vapor may persist for decades (Sasso et al., 1996).

We chose to monitor mercury vapor within interior hallways of residential buildings rather than in individual apartments, because of the difficulty in gaining access due to the consistent reports of distrust of outsiders in communities that may use  $\text{Hg}^0$  culturally (Lythcott, 2003; Riley et al., 2001; U.S. EPA, 2002). We previously measured  $\text{Hg}^0$  vapor levels in the common areas of residential buildings in a community where cultural mercury use exists and found indoor concentrations significantly greater than outdoors (Garetano et al., 2006). In an attempt to determine whether mercury vapor in common areas of residential buildings can serve as a signal of significant cultural use in addition to spillage from other sources, we have revisited the community previously studied, conducted additional sampling and compared our findings with a reference community. Also, at the request of public health officials concerned about cultural  $\text{Hg}^0$  use, we monitored  $\text{Hg}^0$  vapor levels in multifamily residential buildings in another community (S2). Although these additional buildings were targeted rather than randomly selected, we include these findings, as they are relevant to our inquiry. We also consider building and environmental factors that that might influence  $\text{Hg}^0$  vapor levels.

We hypothesize that cultural use of mercury in apartments could lead to elevated  $\text{Hg}^0$  vapor levels in the common areas of residential buildings, and that conversely, elevated levels in common areas would signal that cultural mercury use may be occurring. Our measurement of  $\text{Hg}^0$  vapor in common areas does not provide a direct estimate of exposure, but allows us to identify signals of  $\text{Hg}^0$  release and determine whether these are more prevalent in communities that may use  $\text{Hg}^0$  culturally.

We believe this approach can provide useful information regarding the need to initiate specific public health activities, such as education and outreach, regarding cultural mercury use as well as for further study. These elevations are identifiable with sensitive monitoring devices and serve as signals of  $\text{Hg}^0$  release whether recent or in the past. Nonetheless, because of the indirect nature of sampling common areas, the absence of elevated levels in common areas, does not mean the absence of cultural uses of mercury. We tested the null hypothesis that there would be no difference in mercury levels between study and reference communities.

## 2. Materials and methods

The proposal was reviewed by the Robert Wood Johnson Medical School Institutional Review Board (IRB) and approved as exempt, because no individual identifier information was obtained.

### 2.1. Site selection

Based on our prior investigation and the documented availability of  $\text{Hg}^0$  for cultural purposes, we selected two contiguous municipalities in northern New Jersey as our study community (S1) (Garetano et al., 2006; Riley et al., 2001; Stern et al., 2003). During the course of our research, local public health officials in Rockland County, New York, approximately 32 km north of S1, requested our assistance in monitoring  $\text{Hg}^0$

vapor in selected buildings. Though not in our initial design, we consider it a secondary study community (S2).

We selected a reference study community (C1) located approximately 16 km to the west of S1. It was selected from among sixty-one communities in a three county area in northern New Jersey. We based our selection on the presence of multifamily housing characteristics similar to those in the study community (S1) but a low likelihood of cultural mercury use, based on demographics and the absence of botanicas that might provide mercury for cultural use.

To control for historic contamination, we determined that multifamily buildings in the study (S1) and reference (C1) communities were of similar vintage and had similar characteristics. For each area, we utilized data from U.S. Census 2000 to identify the percentage of the population of ethnicity or a country of origin among those in which cultural mercury use is reported. We identified the percentage of the population of Hispanic/Latino, West Indian or Asian Indian origin for this purpose (Table 1).

We used the presence of botanicas within a community as an indicator of the likely use of mercury for cultural purposes. Greater than twenty botanicas were identified in S1 and the use or sale of mercury by staff was previously documented (Riley et al., 2006; Riley et al., 2001; Stern et al., 2003). In the course of our earlier investigation, we found approximately two dozen stores that contained “botanica” in their name listed in an online telephone directory. We found no similar listings for botanicas in C1, the reference community, or contiguous towns. We also visited shopping districts in C1 and contiguous towns and found no botanicas. The health officials we interviewed in C1 were not aware of botanicas, the availability of mercury elsewhere, or its cultural use in this community.

In both C1 and S1, we identified multifamily buildings listed in county tax records as a residential apartment building, at least three stories high, with seven or more

residential units. Based on our prior investigation, we determined this building configuration typically contained accessible common areas that adjoin entrances to residential units (Garetano et al., 2006). 672 buildings met these criteria in S1 while 49 met the criteria in C1.

We used data from our initial investigation to determine sample size. Consistent with our prior findings, we assumed 30% of buildings in the study area (S1) would have maximum interior Hg vapor concentrations exceeding outdoor upper limits and the prevalence of such findings in the reference community (C1) would be low, approximately 5%. Using these estimates, we determined a sample size of sixty buildings in the study area and forty buildings in the reference community would provide adequate power to control of the probability of Type I and Type II error ( $\alpha=0.05$ ,  $1-\beta=0.84$ ).

In each community (S1 and C1), we randomly selected buildings from the pool of multifamily buildings that met our criteria. We utilized a random number list and selected buildings for evaluation in the order in which a tax record identifier (block number) matched the random number list. We over-sampled in the study community due to the greater number of buildings to increase the precision of our estimate for that area. We were able to access the interior common areas throughout each of 101 buildings. We evaluated 62 buildings in S1 and 39 buildings in C1. The buildings in S1 did not duplicate those assessed in our earlier investigation (Garetano et al., 2006). In the secondary study community (S2), we evaluated a targeted non-random sample of 21 buildings identified by public health officials.

## 2.2. Mercury vapor monitoring

We directly measured Hg<sup>0</sup> vapor in air using a portable atomic absorption spectrophotometer with Zeeman background correction (model 915+, Ohio Lumex Co. Inc. Twinsburg, OH) operated according to the manufacturer’s instructions. Direct measurement of Hg<sup>0</sup> vapor with this instrument is accurate compared with sampling and analysis by laboratory methods and the instrument is suitable for characterizing ambient Hg<sup>0</sup> vapor levels in real time with a detection level of 2 ng/m<sup>3</sup> (Baker et al., 2005; Garetano et al., 2006; Singhvi et al., 2005). This instrument, the size of a large briefcase, is readily portable, and provides real-time readings, allowing many samples to be obtained in a short period of time.

We conducted both indoor and outdoor field monitoring in the reference (C1) and study communities (S1) on twelve days from mid-November 2004 through February 2005. We visited each building once with the exception of a building in which we identified a previously unrecognized mercury spill. In that building, we coordinated subsequent visits with public health officials to verify the efficacy of remedial measures. For consistency, we report data collected on our first visit to that site.

We operated the instrument continuously in a mode that allowed display of both real-time and 10-second average Hg<sup>0</sup> vapor concentration. We positioned the sample inlet at a height of about 1 m. We evaluated one-sample location on each level (floor) of a building when the common area was contiguous to all of the residential apartments on that floor. In segmented buildings divided into wings, we monitored in

**Table 1 – Comparison of multifamily residential building characteristics and demographics among reference and study areas**

	Reference Area (C1)	Study area 1 (S1)	Study area 2 (S2)
<b>Multifamily building characteristics</b>			
Year of construction (95th percentile)	1947	1955	1994
Percent with fluorescent lights in common areas	54%	71%	19%
Ventilation status: (CO <sub>2</sub> in/CO <sub>2</sub> out, 95% CI)	2.1 (1.9, 2.3)	2.3 (2.2, 2.4)	Not assessed
<b>Demographic characteristics</b>			
Median Family Income (1999\$)	96,252	33,165	56,943
Families below poverty level	3.90%	17.30%	13.60%
% Hispanic or Latino	5.10%	80.50%	11.40%
% West Indian of Haitian origin	1.20%	0.10%	13.80%
% Other West Indian origin	5.10%	0.50%	17.50%
% Asian Indian	1.40%	1.50%	11.40%

each wing. At each sample location, we recorded the time-integrated  $\text{Hg}^0$  vapor concentration for each of three consecutive 10-second intervals. We utilize the mean of these three values as the  $\text{Hg}^0$  vapor concentration.

In the reference (C1) and study area (S1), we recorded  $\text{Hg}^0$  measurements at 370 locations in common hallways (C1=136, S1=234). We also measured mercury vapor outdoors in proximity to buildings on each sampling date and recorded data at 109 locations (C1,  $n=46$ ; S1,  $n=63$ ). We visited area S2 once in February 2005 and recorded  $\text{Hg}^0$  measurements at 56 locations in common hallways and 7 outdoor locations using the same procedures. We include data from our prior investigation, [Garetano et al. \(2006\)](#), to estimate the prevalence of households in the study community (S1) that might have elevated mercury vapor levels.

### 2.3. Mercury vapor monitoring — quality assurance

Before and after each sampling session, we calibrated the spectrometer with an internal mercury cell and evaluated the relative deviation (RD) between measured and expected  $\text{Hg}^0$  vapor concentration. On all tests, the measured and expected  $\text{Hg}^0$  vapor concentration varied by less than 14% (mean  $\pm$  SD,  $8.1 \pm 2.4\%$ ). We found no significant difference in performance tests before and after each monitoring period (Wilcoxon Signed Rank test,  $p=0.68$ ).

We evaluated the precision of triplicate measurements at 486 sample locations where  $\text{Hg}^0$  concentration exceeded the spectrometer detection limit ( $2 \text{ ng/m}^3$ ). The average relative deviation was 12.6% (95% CI, 11.7%, 13.5%) with no difference in variability between measurements in areas C1 or S1 (MW *U*-test,  $p=0.98$ ). The relative deviation of measurements in area S2 was 9% (95% CI, 7.4%, 10.6%). These data in conjunction with our continual observation of the consistency of real-time  $\text{Hg}$  vapor measurements provide us assurance that our measurements are accurate and precise.

### 2.4. Additional data utilized

We measured indoor and outdoor carbon dioxide ( $\text{CO}_2$ ) concentration in areas C1 and S1 to assess building ventilation status. We used a direct reading instrument (Qtrak™ model 8851, TSI Inc., St. Paul, Minn.) that was within its recommended factory calibration schedule and also performed calibration checks each day. We logged  $\text{CO}_2$  concentration simultaneous with  $\text{Hg}^0$  monitoring in each building. We also recorded the outdoor  $\text{CO}_2$  concentration in each area on each date. We calculate the ratio of indoor to outdoor  $\text{CO}_2$  ( $\text{CO}_2_{\text{in}}/\text{CO}_2_{\text{out}}$ ) for each building, and use this value to compare ventilation status between buildings in each area.

We examined additional factors that might influence mercury concentration in each building including; type of ventilation system, open windows or doors, and fluorescent lighting. Fluorescent bulbs contain mercury, and we suspected that occasional bulb breakage would result in mercury contamination ([Aucott et al., 2003](#)).

We use hourly outdoor temperature obtained from a National Weather Service monitoring station within 20 km of C1 and S1 to evaluate potential temperature differences between the reference and study community during the monitoring period.

## 2.5. Statistical Analysis

We used SPSS for Windows® version 11.0.1 for data analysis (SPSS Inc., Chicago, IL.). We evaluated data distributions graphically and determined goodness of fit with a normal distribution using the one-sample Kolmogorov–Smirnov test. We used the *t*-test for comparison of means for variables that fit a normal distribution and otherwise used the Mann–Whitney *U* nonparametric comparison test. We compared related variables with the nonparametric Wilcoxon Signed Rank test (WSR test). We use the Kruskal–Wallis nonparametric one-way analysis of variance test for comparisons involving more than two groups. We compared count data among groups with contingency table analysis and utilize the chi-square statistic ( $\chi^2$ ) and report the continuity corrected  $\chi^2$  (Yates correction) where appropriate.

Where reported, the mean  $\text{Hg}^0$  vapor concentration for an entire building represents the arithmetic mean of the  $\text{Hg}^0$  vapor concentration on each floor. For those buildings with multiple wings, the average of all sample locations on that floor represents the  $\text{Hg}^0$  concentration for that floor. The maximum or peak indoor  $\text{Hg}^0$  concentration is the maximum  $\text{Hg}^0$  vapor concentration at any location within a building and represents the average of three sequential 10-second measurements at that location. We consider *p*-values of 0.05 or less as significant, but report higher *p*-values for information purposes.

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## 3. Results

### 3.1. Population and building characteristics

**Table 1** provides a summary of relevant population demographics, building vintage, ventilation status and the prevalence of fluorescent lighting in each community as fluorescent bulbs are a source of mercury.

The residents in the study community (S1), are predominantly Latino (>80%) as compared to approximately 5% in the reference community. Overall, the number of residents of ethnic origins (largely Latino) associated with cultural mercury use was significantly greater than in the reference community (C1) ( $\chi^2=97.6$ ,  $p<0.001$ ). This was also true when we compared S2, in which greater than 40% of the residents are of West Indian, or Asian Indian origin with C1 ( $\chi^2=38.3$ ,  $p<0.001$ ). While the majority of the population in both S1 and S2 were of ethnic origin associated with cultural mercury use, the West Indian and Haitian population in S2 was significantly greater than that in S1 ( $\chi^2=34.8$ ,  $p<0.001$ ).

Multifamily buildings in both the C1 and S1 are typically greater than fifty years old with no significant difference in building age between the communities (MW *U*-test,  $p=0.56$ ). The multifamily housing stock in the S2 area is of more recent vintage than either C1 or S1. All buildings in each area use natural gas supplied by a public utility for cooking. We found heating systems that utilize hot water or steam radiators in all buildings. No ventilation systems that introduce outside air to common areas or circulate air between areas of a building were noted. Additionally, no open windows or exterior doors were observed during the monitoring period.



**Fig. 1** – Foreground left: amalgam icon — Parad Shivling. This item weighed 10 g and emitted 0.3  $\mu\text{g}/\text{h}$   $\text{Hg}^0$  vapor at 24 °C. Foreground right: gelatin capsules containing  $\text{Hg}^0$ . The clear capsule contains 9 g  $\text{Hg}^0$  and was purchased in the study area for \$1.00. We purchased the colored capsules in the Dominican Republic at a similar cost. Rear left: bottle of elemental mercury. This bottle contains approximately 2 kg  $\text{Hg}^0$  and was the source of spilled Hg in the reference community (C1). Rear center and right: Agua de Florida, and 7 Escencias. We purchased these items in the Dominican Republic also. The store clerk suggested we mix these items with mercury from the capsules and apply the mixture to floors in the home twice per week. These products typically contain water, alcohol, and essential oils. We do not believe they contain mercury though we did not analyze them.

We found the  $\text{CO}_2$  concentration in building common areas ( $555 \pm 140$  ppm) to be approximately double that of outdoors ( $255 \pm 44$  ppm) with an average  $\text{CO}_2$  in/ $\text{CO}_2$  out ratio of 2.2 (SD  $\pm 0.6$ ). This ratio did not significantly differ between C1 ( $2.1 \pm 0.7$ ) and S1 ( $2.3 \pm 0.4$ ) (t-test,  $p=0.13$ ).

The mean outdoor temperature during the periods we monitored ranged from  $-2$  °C to 10 °C ( $3.1 \pm 3.7$  °C). The difference in outdoor temperature between C1 and S1 on the dates we monitored them separately was not significant (MW U-test,  $p=0.38$ ).

We noted fluorescent lighting in common areas in 53.8% and 71% of buildings in C1 and S1 respectively ( $\chi^2$ , 3.0,  $p=0.08$ ). This percentage was lower in S2 (19%) than C1 or S1 ( $\chi^2$ , 17.4,  $p<0.001$ ).

### 3.2. Mercury vapor concentration in buildings

#### 3.2.1. Building with a $\text{Hg}^0$ spill

We detected high  $\text{Hg}^0$  vapor levels in one building in C1. We found 4 to 1270  $\text{ng}/\text{m}^3$   $\text{Hg}^0$  in common areas and up to 5500  $\text{ng}/\text{m}^3$  in the caretaker's office. We localized the source to the basement floor just outside the elevator and verified subsequent tracking of  $\text{Hg}^0$  onto the elevator floor and floors outside the elevator in building hallways.  $\text{Hg}^0$  vapor levels in the common areas above the ground level (mean  $\pm$  SD,  $162 \pm 43$   $\text{ng}/\text{m}^3$ ) were greater than those on the ground level where elevator use is unlikely (mean  $\pm$  SD,  $14 \pm 10$   $\text{ng}/\text{m}^3$ ). The building superintendent indicated he had recently found a “heavy bottle” in the basement outside the elevator. He noted no visible spillage, nor did we. The bottle was partially full, containing about 2 kg of  $\text{Hg}^0$  (Fig. 1). The source of the bottle is not known, but based on its location and the type of container; it is not likely to be related to cultural uses.

Our findings were immediately referred to public health officials enabling prompt remedial measures. In subsequent data analyses we note where data from this outlier building is excluded.

#### 3.3. Comparison of indoor and outdoor mercury vapor concentration

Table 2 provides a summary of outdoor  $\text{Hg}^0$  vapor levels in each area. Outdoor levels were slightly higher in the study community (S1) than the reference community (C1) (MW U-test,  $p=0.2$ ). Outdoor  $\text{Hg}^0$  vapor levels were greater in S2 than either S1 or C1, but the small sample size in area S2 limits meaningful comparison.

Table 3 summarizes the mean and maximum  $\text{Hg}^0$  vapor concentration in building common areas. We compared both peak and mean indoor  $\text{Hg}^0$  vapor levels with those outdoors on both an aggregate and area-specific basis and found them to be significantly greater than those outdoors (MW U-test,  $p<0.001$ ). We also compare both mean and maximum indoor  $\text{Hg}^0$  vapor concentration for each building in C1 and S1 with the area-specific 95th percentile outdoor concentration. In area S2 we utilize the mean outdoor  $\text{Hg}^0$  vapor concentration plus two standard deviations as a basis of comparison since we had insufficient outdoor samples to estimate the 95th percentile. For purposes of further comparison we refer to these outdoor  $\text{Hg}^0$  vapor levels as the “outdoor upper limit”.

The maximum interior  $\text{Hg}^0$  concentration exceeded the area-specific outdoor upper limit in 43% of buildings (53 of 122) while the mean interior  $\text{Hg}^0$  concentration exceeded the area-

**Table 2** – Comparison of outdoor  $\text{Hg}^0$  vapor concentration by area ( $\text{ng}/\text{m}^3$ )

Percentiles										
Area	No.	Mean $\pm$ SD	GM	Max	10th	25th	50th	75th	90th	95th
C1	43	$2.3 \pm 1.6$	1.9	7.0	1.0	1.0	2.0	4.0	5.0	5.8
S1	63	$2.9 \pm 2.4$	2.2	12.0	1.0	1.0	2.0	3.0	6.0	9.6
S2	7	$3.9 \pm 3.7$	2.7	12.3	2.0	2.0	3.0	3.0	–	–

Statistical comparisons:

All groups (Kruskal–Wallis test,  $p=0.12$ ).

C1 versus S1 (Mann–Whitney U-test,  $p=0.20$ ).

General range of values in United States is 2–10  $\text{ng}/\text{m}^3$  (ATSDR, 1999).

**Table 3 – Mean and maximum mercury vapor concentration in building common areas (ng/m<sup>3</sup>)**

Mean Hg <sup>0</sup> vapor concentration in building common areas												
Percentiles												
Area <sup>a</sup>	No.	Mean ± SD <sup>b</sup>	GM	5th	10th	25th	50th	75th	90th	95th	Compared to C1	
C1	38 <sup>c</sup>	5.0 ± 3.0	4.1	0.6	1.9	2.6	4.2	7.4	9.1	11.0		
S1	62	9.8 ± 11.3	6.3	1.5	2.0	3.3	5.3	14.5	18.6	32.0	p=0.02	
S2	21	15.4 ± 18.4	11.4	6.3	7.1	7.7	8.7	15.2	43.6	81.1	p<0.001	
Maximum Hg <sup>0</sup> vapor concentration in building common areas												
Percentiles												
Area	No.	Mean ± SD <sup>b</sup>	GM	5th	10th	25th	50th	75th	90th	95th	Max	Compared to C1
C1	38 <sup>c</sup>	6.4 ± 4.1	5.1	0.7	2.3	3.3	5.5	8.8	12.4	14.2	18.0	
S1	62	13.3 ± 14.9	8.8	2.7	3.1	4.7	7.0	17.8	33.5	42.6	79.3	p=0.01
S2	21	19.0 ± 23.5	13.1	7.0	7.4	7.9	9.7	16.7	63.7	96.7	99.7	p<0.001

<sup>a</sup>(C1) reference community, (S1) study community, (S2) study community 2.  
<sup>b</sup>Kruskall–Wallis ANOVA among all three areas, *p*<0.001.  
<sup>c</sup>Building in C1 with spill excluded; difference remains significant if included.

specific outdoor upper limit in 34% (*n*=42). We noted no significant difference between S1 and C1 with regard to the proportion of buildings in which maximum or mean Hg<sup>0</sup> vapor concentration in building common areas exceeded the area-specific outdoor upper-limit concentration ( $\chi^2$ , 0.06, *p*=0.97 and  $\chi^2$ , 1.7, *p*=0.41 respectively).

As expected, low mercury concentrations (mean ± SD, 4.5 ± 2.3 ng/m<sup>3</sup>, 95th percentile 8.7 ng/m<sup>3</sup>) were found in those buildings (66%, *n*=80) with mean levels less than the outdoor upper limit.

### 3.4. Comparison of indoor mercury vapor levels among areas

Both the average maximum (13.3 ng/m<sup>3</sup>) and mean (9.8 ng/m<sup>3</sup>) Hg<sup>0</sup> vapor concentration are significantly greater in buildings in study area (S1) than in the reference area (C1) (max=6.4 ng/m<sup>3</sup>; mean=5.0 ng/m<sup>3</sup>) whether the outlier with the verified Hg spill is excluded (Mann–Whitney *U*-test, *p*=0.01 for max and *p*=0.02 for mean) or included (Mann–Whitney *U*-test, *p*=0.02 for maximum and, *p*=0.05 for mean). Mean and maximum indoor Hg<sup>0</sup> vapor levels in S2 are also significantly greater than those in C1 (MW *U*-test, *p*<0.001) when the outlier is included.

Fig. 2 depicts a plot of the maximum Hg<sup>0</sup> values from all buildings and reveals an inflection point close to 25 ng/m<sup>3</sup> Hg<sup>0</sup>. This value is also the 90th percentile of the maximum Hg<sup>0</sup> concentration for all buildings excluding that with a known mercury spill. We therefore consider Hg<sup>0</sup> vapor readings greater than 25 ng/m<sup>3</sup> at any location a signal of mercury release above background.

In the reference community (C1) only the building in which we located a Hg<sup>0</sup> spill exhibited a signal of mercury release. Excluding this building, significantly more buildings in S1 (9 of 62, 14.5%) had signals of Hg<sup>0</sup> release than in C1 ( $\chi^2$ ; 6.1; *p*=0.01; continuity corrected  $\chi^2$ ; 4.4; *p*=0.04). When this building is included the difference between S1 and C1 is somewhat muted ( $\chi^2$ ; 3.8; *p*=0.05; continuity corrected  $\chi^2$ ; 4.4; *p*=0.11). In area S2, the number of buildings with signals (3 of 21, 14.3%) was essentially no different than in S1 ( $\chi^2$ ; 0.001; *p*=0.98).

### 3.5. Evaluation of variables that might influence mercury vapor concentration

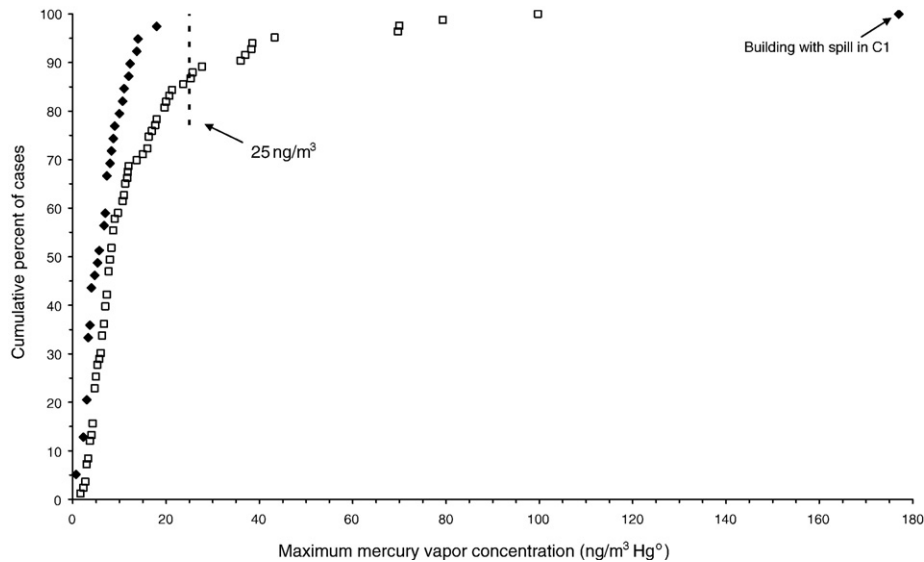
A high indoor to outdoor CO<sub>2</sub> ratio (CO<sub>2 in</sub>/CO<sub>2 out</sub>) is indicative of lower “fresh air” ventilation. There was a positive but weak association between both maximum and mean indoor Hg<sup>0</sup> concentration and the indoor to outdoor CO<sub>2</sub> ratio (Kendall’s tau-β, 0.15, *p*=0.07 and tau-β, 0.16, *p*=0.06). However, ventilation status did not differ significantly among buildings in areas C1 and S1.

We compared mean and maximum Hg<sup>0</sup> concentrations in buildings with (*n*=69) and without (*n*=53) fluorescent lights. Contrary to expectation, buildings with fluorescent lights had significantly lower mean and maximum Hg<sup>0</sup> vapor levels (9.0 ± 11.8 ng/m<sup>3</sup> and 12.2 ± 16.0 ng/m<sup>3</sup> respectively) than those without (11.7 ± 19.2 ng/m<sup>3</sup> and 15.1 ± 26.7 ng/m<sup>3</sup>) (Mann–Whitney *U*-test, *p*=0.04 and *p*=0.08 respectively). Further, we observed no relationship between the presence of fluorescent lights and the presence of signals of Hg<sup>0</sup> vapor release ( $\chi^2$ ; 0.95; *p*=0.33).

In those buildings with a Hg<sup>0</sup> vapor signal, we further compared Hg<sup>0</sup> vapor levels on the ground floor with those on upper floors under the presumption that if spills from gas meters or similar apparatus were present, Hg<sup>0</sup> vapor levels would be highest closest to the source, typically the basement. We found slightly lower Hg<sup>0</sup> vapor levels on the ground floor (52 ± 19 ng/m<sup>3</sup>) than on upper floors (65 ± 44 ng/m<sup>3</sup>). We found no significant difference in Hg<sup>0</sup> vapor concentration by floor when we compared all floors simultaneously (Kruskall–Wallis test, *p*=0.99) or individually on post-hoc analysis (Dunnnett C, *p*=0.85).

### 3.6. Estimated prevalence of households in study area (S1) that may generate Hg<sup>0</sup> vapor signals greater than 25 ng/m<sup>3</sup> in building common areas

During this evaluation and our prior survey in (S1) we monitored Hg<sup>0</sup> vapor levels in the common areas of ninety-six non-duplicated residential buildings. The areas monitored adjoined 1325 of the 39,591 households in area S1. We detected twenty-seven discrete signals (>25 ng/m<sup>3</sup> Hg<sup>0</sup>) of which we



**Fig. 2 – Cumulative probability plot of maximum  $\text{Hg}^0$  concentration in building common areas ( $n = 122$ ).**  
**◆ Reference community (C1), □ study communities (S1, S2).**

attribute twenty-three to residential apartments. In the remainder, the  $\text{Hg}^0$  vapor source was localized to a spot on stairs or floors in the common area. We did not see visible mercury in any of these locations.

Thus, possibly 1.74% (95% CI: 1.05%, 2.40%) of households emitted enough  $\text{Hg}$  vapor to result in a signal within the common area. By extrapolation to all households in area S1, we estimate 689 (95% CI: 416, 962) or 17 per 1000 households (95% CI: 10–24 per 1000) may contain mercury vapor at a level sufficient to result in a signal  $>25 \text{ ng/m}^3 \text{ Hg}^0$  in building common areas.

#### 4. Discussion

The outdoor  $\text{Hg}^0$  vapor levels we noted are consistent with expected values for suburban and urban areas reported elsewhere to range from about 2 to  $10 \text{ ng/m}^3 \text{ Hg}^0$  (ATSDR, 1999; Garetano et al., 2006; Hladikova et al., 2001; Hopke et al., 2003; Peacheyran et al., 2000). Though we noted peak outdoor mercury vapor levels to be lower in study area (S1) in this investigation compared with our initial investigation ( $17 \text{ ng/m}^3$ ), our analysis provides assurance that the relationship of indoor and outdoor  $\text{Hg}^0$  vapor levels are consistent with those previously reported for this community.

Our findings expand the sparse data concerning mercury vapor in residential buildings and support previous findings that mean indoor concentrations are significantly greater than outdoors (Carpi and Chen 2001; Foote 1972; Garetano et al., 2006). This was also true in the reference community where cultural mercury use is unlikely, possibly reflecting mercury emissions from sources such as broken thermometers or fluorescent bulbs. Though distinct from our primary inquiry, we believe the mercury levels we found in those 80 of 122 buildings with mean levels less than outdoor upper limits provide a preliminary reference range (mean  $\pm$  SD,  $4.5 \pm 2.3 \text{ ng/m}^3$ ; 95th percentile,  $8.7 \text{ ng/m}^3$ ) for  $\text{Hg}^0$  vapor in common

areas of residential buildings relatively free of contamination from current or historic technologic or cultural  $\text{Hg}$  use.

Although we cannot estimate exposure from our data, we have demonstrated that both mean and maximum mercury vapor levels in the common areas of multifamily buildings as well as the prevalence of buildings with signals of mercury release ( $>25 \text{ ng/m}^3 \text{ Hg}^0$ ) are significantly greater in communities where cultural mercury use is likely compared to a community where such mercury use is unlikely. Except for the building in the reference community in which we identified a previously unrecognized mercury spill, we detected  $>25 \text{ ng/m}^3 \text{ Hg}^0$  only in the study area which is consistent with our hypotheses.

We cannot attribute the greater prevalence of elevated mercury vapor levels in either of the study communities to cultural use with absolute certainty, but we have no alternate explanation. We selected a reference community in which multifamily buildings had similar characteristics to those in the primary study community. We further controlled for other building and climatic factors that might influence mercury vapor concentration and believe they did not influence our findings. In the secondary study community (S2), buildings were of more recent vintage, probably with less building related uses of mercury, yet mercury levels were greater than the reference community.

Household contamination secondary to occupational exposure could contribute to  $\text{Hg}^0$  vapor levels in residential buildings. We consulted the agencies responsible for environmental regulation associated with the reference and study communities (C1 and S1). Other than the potential use of sealed devices such as gauges and switches, neither we nor the regulatory agencies are aware of employers utilizing elemental mercury except dental offices. Dentistry remains a source of occupational mercury exposure in these as well as most communities though we found no reports of household contamination from this exposure. We did not control for occupational exposure but have no reason to believe such

exposure would differ between communities or influence our findings.

#### 4.1. Comparison with reference concentrations used for public health evaluations

The Agency for Toxic Substances and Disease Registry has set a Minimum Risk Level (MRL) of 200 ng/m<sup>3</sup>, as the level below which continuous residential exposure is not associated with detectable adverse effects. “This level is the amount of mercury vapor in the air that is unlikely to produce adverse health effects based on a continuous exposure over a person’s lifetime. The MRL does not indicate a threshold level above which toxic effects are likely to occur”, but rather provides a trigger or screening level to suggest to public health officials that a closer examination of the potential exposure may be warranted,” (ATSDR, 1999). The mercury MRL is based on tremor in adult male workers and includes a 30-fold uncertainty factor.

In all locations other than the building with spilled Hg<sup>0</sup>, none of the mercury concentrations approached the ATSDR MRL. However, it is important to point out that these measurements reflect levels only in common areas and not in apartments where concentrations are likely to be higher and where exposure is likely to occur over a longer duration. We also note that investigations subsequent to publication of the MRL suggest some individuals with specific genetic polymorphisms exhibit increased susceptibility to adverse neuro-behavioral effects from low-level Hg<sup>0</sup> exposure (Echeverria et al., 2006, 2005).

We believe the signals provided by spot measurements of mercury vapor concentration in building common areas are a relevant screening tool to identify the presence of mercury release within a building regardless of its source. Obtaining data on the relationship between mercury levels in common areas versus those in living areas could be a useful next step.

The generalization of our findings is limited by the cultural composition of the residents in areas we investigated as well as the number of locales investigated. Our findings are applicable only to larger multifamily residential buildings though there is no reason to believe cultural mercury use is restricted to occupants of that building type. Our evaluation is a snapshot of mercury vapor concentrations in the buildings surveyed and does not evaluate temporal variation of mercury concentration. Mercury emission from dispersed droplets may rapidly decrease as demonstrated by Singhvi et al. (2005), or it may increase as surface area of droplets is increased by disturbing them. Additionally, cultural practices may be conducted on auspicious days or even in particular seasons (Figuroa, personal communication). Since we conducted our evaluation in the reference community and study community in the same season, alternating visits to each without regard to day of the week, we find no reason to believe that short-term temporal variation in mercury concentration would bias our findings either positively or negatively.

We believe the “signals” of Hg<sup>0</sup> release we observed in the communities where cultural use is likely provide empirical data that mercury is dispersed in more residential buildings in these communities than elsewhere. Our findings are consistent with previous reports (Wendroff, 2005; Riley et al., 2001;

U.S. EPA, 2002), and lead us to conclude that some individuals in these communities may be exposed to elevated Hg<sup>0</sup> vapor from cultural practices. Considering the turnover in apartment habitation, current residents may be unknowingly exposed to residual mercury from prior spills or practices.

We believe our findings merit targeted public health intervention including culturally appropriate educational outreach, voluntary biomonitoring, and air monitoring for purposes of exposure assessment where indicated, in communities where cultural mercury use is likely. We agree with the position of Riley et al. (2006, 2001) and the U.S. EPA (2002) that a regulatory approach to this issue may drive this issue further underground lessening the likelihood of effective intervention. There are a variety of possible non-regulatory approaches based on outreach and education. Given the potential sensitivity of communities to this issue, approaches should be carefully selected with attention to the specifics of community structure and institutions both formal and informal.

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