Summary of References on Mercury Emissions from Crematoria

September 25, 2012

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Introduction

In July 2000, the Dane County, WI Board of Supervisors banned the sale of fever and basal thermometers containing mercury. As a follow-up to that action, a survey was done of other issues related to mercury in products and it was learned that cremation was a little known, but potentially important source of mercury to the environment. Thus began a summary of information sources of mercury from cremation, which has been periodically updated since then.

Summary

Modern cremation has been a method of handling remains in the US since the 1870's (Prothero), but with a rate of less than 5% of all deaths until approximately 1972. The percentage of cremations increased rapidly after that year (Prothero), reaching just under 32% in 2005 and expected to increase to nearly 56% in 2025 (Cremation Association of North America).

Crematoria represent a significant source of mercury emissions to the environment. While estimates of the quantities vary significantly, it appear that each cremation releases between 2 and 4 grams, with the maximum seen by this reviewer at 8.6 grams in an individual cremation in Switzerland. There has been an increase in the number of cremations annually and forecasts include both a further increase in the number of cremations over time and an increase in the amount of mercury released in the next few decades due to an increase in the number of the deceased having a larger number of their own teeth with amalgam restorations. This increase is

expected to be followed by a decrease in mercury emissions from industrialized countries as the next generation of people has both few cavities and an increased substitution of amalgam restorations with restorations that do not use mercury.

In the US, a mercury flow worksheet developed for Region V of the EPA estimates that in 2005, just under 3,000 kilograms of mercury were released to the environment from cremation to the US. Bender estimates that this will increase to 7,700 kilograms by 2020.

Most of the mercury from crematoria is released to the air, although some may collect on the walls of the oven and chimney. Soil surveys have shown that while there is often an elevation of mercury in the top soils near crematoria, most (over 99%) of the mercury emitted to the air does not settle to the soil in the nearby area, but is instead added to the general atmosphere. Mercury levels in the ash have been only rarely tested, and have been shown to be negligible in those tests.

Mercury emissions from crematoria are regulated in few places in the world, although the amount of regulation is slowly growing. Possible control of mercury from crematoria includes the removal of teeth with amalgam restorations before cremation, the use of selenium capsules to bind up the mercury and exhaust gas capture systems. The effectiveness of the selenium capsules is controversial and the effectiveness of the exhaust gas capture systems is not well documented.

Number of cremations in Dane County, in Wisconsin, and in the US

According to emails from the Dane County Coroner (Stanley, 2004, 2005, 2006, 2007, Irmen 2010, 2012), the number of cremations of Dane County deaths at crematoria within Dane County for the years 2003 to 2011 have been as follows:

2003	1,615
2004	1,566
2005	1,548
2006	1,636
2007	1,817*
2008	1,964*
2009	2,004*
2010	1,857
2011	1,946

*includes corpses from out of the county cremated within the county

Thus, over the six year time frame of 2003 to 2011, the number of cremations has increased by 20%, or, an average of 2.3% a year. From 2005 to 2011, the increase has been 25%, or an average of 3.9%.

In previous communications, it was noted that there were 5 crematoria in Dane County, and that about a third of all cremations are of deaths from nearby counties. While a previous message from the Stanley had estimated that cremations were increasing at the rate of about 10% a year, the data above show that the trend is much less than that

According to Irmen, as of 2010, there are 7 crematoria within Dane County. These are Cress (2), Ellestad, Gunderson, Memory Gardens, Ryan, and UW Anatomy. Krantz (2010) notes that some corpses from deaths in Dane County are transported out of county for cremation. Irmen (2012) notes that corpses brought into Dane County from nearby counties are not included in the above data for 2010 or 2011, but were for 2007-2009.

For the state of Wisconsin, the Wisconsin Department of Health Services puts Wisconsin deaths in 2010 at 47,212, with the cremation rate at 44.9%, for a total of 21,183 cremations. As shown in the chart below, the cremation rate has steadily increased since 2001, while the burial rate has steadily decreased, and the two rates are nearly equal.

Table 7. Deaths by Disposition of Body, Wisconsin 2001-2010

Disposition of Body	Years									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
TOTAL DEATHS	**46,537**	**46,893**	**46,040**	**45,488**	**46,544**	**46,051**	**46,117**	**46,526**	**45,598**	**47,212**
PERCENT	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.00**
Burial	29,044	28,874	27,689	26,531	26,769	25,653	25,001	24,110	22,417	22,472
Percent	62.4	61.6	60.1	58.3	57.5	55.7	54.2	51.8	49.2	47.5
Cremation	13,160	13,790	14,287	15,044	15,884	16,550	17,337	18,687	19,636	21,183
Percent	28.3	29.4	31.0	33.1	34.1	35.9	37.6	40.2	43.1	44.9

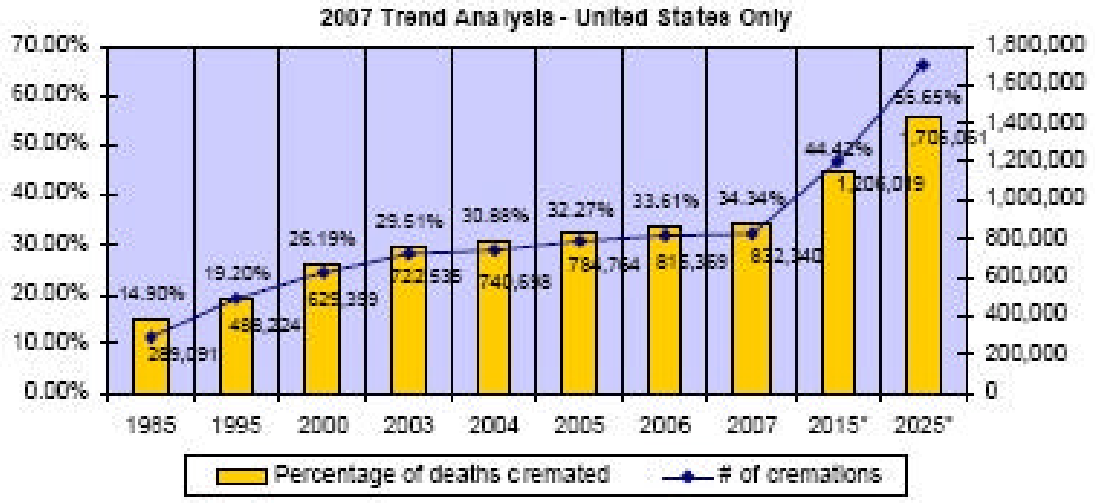
The number of cremations has increased at an annual rate of 6.4% since 1991, the first year for which Wisconsin reports these data, and when there were 6,491 cremations, for a rate of 15.1% of all deaths.

In the US, the latest data available at this time are for 2007, for which just over 832,000 cremations are estimated to have been performed at just under 2,000 crematoria (Cremation Association of North America (CANA), 2010). Cremation rates vary greatly among various groups of people. In the US, in an article in *USA Today* in 2005 (Grossman), it was noted by Jack Springer, Executive Director of the Cremation Association of North America that cremation rates in the US range from 3% in Tennessee to 61% in Nevada. Some of the differences in the rates of cremation are said to be related to the religion of the deceased, with some religions forbidding cremation and others including it as part of their tradition. Also important are the ties of the deceased and the family of the deceased to the community where the death occurred. Those with stronger ties to the community generally have lower cremation rates.

The rate and number of cremations in the US is expected to grow rapidly, with CANA's 2007 trends analysis projecting that in 2025, about 56% of all corpses will be cremated, for a total of 1,706,000 corpses.

Cremation Data & Predictions: Data Trends

- Percentage of Deaths Resulting in Cremation Since 1985



*Projected figures

Cremation Rates in Europe

On an international level, an article in a Danish newspaper in September 2003 (Thøgersen) noted that 90% of all deaths in their larger cities are cremated. The number of cremations is also growing rapidly in some countries. In an article published in 2003 in Switzerland (Knellwolf), it is noted that in the 1960's, one of every five deceased was cremated, while in 2000, two-thirds of all deceased were cremated.

A French language web page (Miquel) gives a table of cremation rates in several European countries from 1998, with the text noting that countries of strong Catholicism have low cremation rates:

Cremation Rates in Europe - 1998

Italy	4 %
Spain	11 %
France	15 %
Belgium	31 %
Germany	40 %
The Netherlands	48 %
Switzerland	68 %
Denmark	71 %
Great Britain	71 %

This article notes that the reported rates of cremation in China and Japan are 80% and 95%, respectively.

A 2012 informational table on a web page of the Cremation Society of Great Britain gives different data for 2010 and 2009 (indicated with an asterisk) for the above countries:

Italy	13 %
France	30 %
Belgium	47 %*
The Netherlands	57 %
Great Britain	73 %
Denmark	77 %
Switzerland	85 %
Spain	NG
Germany	NG

This table notes that the reported rates of cremation in China and Japan are 49% and 99.9%, respectively.

Thus, we see an increase in cremation rates in all countries for which data are reported, except for in China. The Cremation Society of Great Britain data for 1998, however, list the Chinese cremation rate at 40%. so even for China, these two sets of data show an increased rate.

Mercury use in Dentistry

Data were obtained from a variety of sources, including the US Bureau of Mines, the US Geological Survey, the US EPA, an estimate by Bethlehem Apparatus Company as reported by Johnson, a presentation by Vandeven and the Interstate Mercury Education & Reduction Clearinghouse (IMERC) database for the use of mercury in dentistry from 1941 through 2001. In 1941, mercury use was about 0.15 grams per person per year, a total of 21 metric tons for the US. That number increased to just over 0.50 grams per person per year in the 1970's, with 104 metric tons used in 1974. For 2001, the estimate is between 0.07 and 0.15 grams per person, with the IMERC database reporting 21 metric tons of consumption and Bethlehem Apparatus estimating consumption at 44 metric tons. The US EPA mercury flow worksheet, updated in June 2006, uses an estimate of 32 metric tons for 2000, based on the work of Vandeven. More recent data from the Interstate Mercury Education and Reduction Clearinghouse (IMERC) of the Northeast Waste Management Officials' Association (NEWMOA) suggests that the use of dental mercury has dropped dramatically in the US recently, from 30.39 tons in 2004 to 16.48 tons in 2007 (Wienert). On a percentage basis, dental mercury went from just over 26% of all mercury sold in the US in 2004 to just under 24% in 2007.

In a Power Point presentation of the city of Palo Alto, CA, it notes that a small filling (restorations) typically has 0.37 grams of mercury, calculated at one amalgam unit with 0.55 gram mercury, minus 0.14 gram waste

during the filling process, minus 0.04 grams in trimmings. A large filling starts with two amalgam units, but the final amount of mercury in the filling is not stated, although it is implied to be 0.74 grams.

In 1997, a US study (Albertini) was published with the results of a 1992-3 study of restorations in 1,166 male US Air Force Veterans, of which 1,105 had teeth. The results are in the following table:

Dental Restorative Practices in US Air Force Veterans
1992-1993 Study

Age Group	Number of People	Mean Number of Teeth	Mean Number of Restored Surfaces	Mean Number of Restored Anterior Surfaces with Amalgam	Mean Number of Restored Posterior Surfaces with Amalgam
40-44	105	25.66	30.91	0.52	18.89
45-49	392	26.12	34.66	0.70	19.81
50-54	182	25.80	40.32	0.90	21.36
55-59	193	23.92	39.83	0.98	18.42
60-64	175	23.25	42.21	1.16	17.35
65-79	58	21.71	41.00	0.74	14.00

The authors note that other studies had found that the people in this study probably had better dental care than the population as a whole and had both more restored dental surfaces and fewer missing teeth than the population as a whole. On this issue, a 1998 article by Kingman reported results of a study of Vietnam-era veterans under the auspices of the National Institute of Dental Research, augmenting the results of the Air Force Health Study. In this study, they reported the following data for the study participants and the US adult male population and found that the veterans in the study had much higher levels of tooth retention than the general public. (Note: edentulous means "without teeth".)

Edentulism and Extent of Natural Teeth
in US Male Adults and the NIDR Study Cohort
1998 report

	NIDR Cohort	NIDR Cohort	US Adult Males	US Adult Males
Age Group	Edentulous	# Natural Teeth	Edentulous	# Natural Teeth
40-44	1.0	25.7	4.8	23.9
45-49	2.8	26.1	9.1	21.7
50-54	6.3	25.7	9.3	21.1
55-59	6.1	23.9	17.9	20.4
60-64	6.5	23.2	23.3	19.3
65-79	10.3	21.3	28.0	18.7 (est)

Marcus, et. al., give data for tooth retention and tooth loss for the general adult public in the 1988-1991 period.

Percentage of US Adults with One or More Teeth
1988-1991
NHANES III

Age Group	Male % Dentate	Male Ave Number of Teeth	Female % Dentate	Female Ave Number of Teeth
40-44	95.2	22.7	93.3	22.3
45-49	90.9	19.7	90.7	20.6
50-54	90.7	19.2	85.8	18.4
55-59	82.1	16.7	82.6	15.0
60-64	76.7	14.8	75.8	14.7
65-69	73.0	14.3	74.9	14.1
70-74	70.9	12.5	67.3	12.7
75+	53.4	8.4	57.8	9.4

More recent data on oral health in the US (Dye, et. al.) provide information on the number of restorations, as shown in the following table. As seen, the number of filled teeth and filled surfaces in permanent teeth has declined in both categories for those 49 and under, while those 50 and older have had an increase in one or both categories. The most dramatic increase in is those 75 and older. As shown elsewhere in this document, two thirds of all deaths are of people 75 and older.

Number of Filled Teeth and Filled Tooth Surfaces in the US
1988-1994 and 1999-2004
Secondary teeth except where indicated

	1988-94		1999-2004		Changes	
Age Group	Filled Teeth	Filled Surfaces	Filled Teeth	Filled Surfaces	Filled Teeth	Filled Surfaces
2-5 (Primary teeth)	0.34	0.87	0.47	1.33	0.13	0.46
6-11 (Primary teeth)	1.06	2.31	1.26	3.32	0.20	1.01
6-8	0.16	0.22	0.13	0.19	-0.03	-0.03
9-11	0.66	1.04	0.50	0.76	-0.16	-0.28
12-15	1.66	2.60	1.38	2.19	-0.28	-0.41
16-19	3.31	5.23	2.61	4.41	-0.70	-0.82
20-34	6.10	11.96	4.61	8.62	-1.49	-3.34
35-49	9.27	23.48	7.78	18.38	-1.49	-5.10
50-64	9.18	27.94	9.20	27.35	0.02	-0.59
65-74	9.21	29.10	8.96	29.36	-0.25	0.26
$\geq$ 75	7.73	24.70	8.42	28.03	0.69	3.33

Two reports on the number of fillings per person in Sweden were found. In 1994, Hogland noted that in Sweden, people in the age range of 30-55 have the highest amount of mercury in their teeth (about 15 grams per person), those younger than 30 have about 10 grams and those older than 55 have 5 grams each. Using these data and information on the number of people who die in different age groups, he calculates that mercury emissions from crematoria in Sweden will increased from 177 kilograms a year in 1985 to 602 kg/year in 2020, following by a decrease to 570 in 2025.

In a report from 1996 (Gran), it is reported that the average filling in Sweden weighs one gram, of which 50% is mercury. In a study of people with an average age of approximately 44, the average was 11-12 fillings per person.

In a rule promulgated by the US FDA in 2009, the agency provides the following estimate of the number of dental restorations through 2023. The estimate does not include the quantity of mercury used.

US FDA Projected Annual Dental Restorations and In-place Amalgam Restorations
(in millions)

Year	US Population	Total Restorations	Amalgam Restorations	Other Restorations	Number of amalgam restorations in place
2009	307.2	149.0	50.5	98.5	890.5
2010	310.2	145.0	49.0	96.0	879.5
2011	313.2	141.0	47.6	93.5	867.1
2012	316.3	137.2	46.2	91.0	853.3
2013	319.3	133.4	44.8	88.5	838.1
2014	322.4	129.7	43.5	86.2	821.6
2015	325.5	126.1	42.2	83.9	803.8
2016	328.7	122.6	41.0	81.6	784.8
2017	331.8	119.1	39.8	79.4	764.6
2018	335.0	115.8	38.6	77.2	743.2
2019	338.2	112.5	37.5	75.0	720.7
2020	341.4	109.4	36.4	72.9	697.1
2021	344.6	106.3	35.4	70.9	672.5
2022	347.8	103.3	34.4	68.9	646.9
2023	351.0	100.3	33.4	67.0	620.3

Mercury in Body Tissues, Bones

According to a study done by the US Centers for Disease Control and Prevention (the 1999 National Health and Nutrition Examination Survey (NHANES 1999)), the geometric mean for mercury in the blood of women aged 16 to 49 was 1.2 ppb, with a 90th percentile reading of 6.2 ppb. For hair samples, the geometric mean was not calculated, but the 90th percentile level was 1.4 ppm.

References have not been found on the relationship of mercury levels in either blood or hair to levels in other body tissues. According to a web page of the World Health Organization, 80-90% of ingested methylmercury becomes combined with red blood cells. This implies that only 10-20% would combine with other body tissue. For metallic mercury vapors, in a US FDA rule released in 2009, it was noted that metallic mercury vapors absorbed into the body are oxidized to mercury ions (Hg^{2+}) with cells and that this mercury is unable to diffuse back across the cell membrane. The mercuric ion is said to have a half-life of two months. Two references are cited: Liu, J. et al., "Toxic effects of metals," Casarett Doull's Toxicology: The Basic Science of Poisons, Chapter 23, pp. 931-979, McGraw-Hill Medical, New York, New York, 2008, and Clarkson, T.W. et al., "The Toxicology of Mercury and Its Chemical Compounds, "Critical Reviews in Toxicology, Vol. 36, pp. 609-662, 2006. Several articles discuss the half-life of mercury in the body, and more details will be sought on this subject.

As an indication of mercury levels from body tissues as part of cremations, if the average weight of a cremation is estimated at 80 kilograms (176 pounds), the data from blood and hair samples would provide a range of 9.6 x 10^{-5} to 1.2 x 10^{-1} grams of mercury in body tissues per cremation. The high end is viewed as extremely conservative as it represents the 90th percentile, not the mean level of mercury in hair.

Longevity of fillings

In a US Geological Survey report published in 2000, it was noted that the average life of a mercury amalgam filing is reported to be from 5 to 8 years, while in a 1995 article in a Swiss dental medicine journal (Matter-Grütter), the average life was stated to be 10 years, and 10 years is the assumption used in Defra's 2nd consultation, published in 2004 (UK Department for Environment, Food and Rural Affairs). In a 1991 article in *Consumer Reports*, (Anonymous) however, the life of mercury fillings was given as 10-20 years.

If these data are correct, they imply at least two things: (1) the amount of mercury fillings in cremations depends on the amount of fillings obtained in the last decade or so of life, and (2) changes in dental filling practices will affect the amount of mercury found in cremations relatively rapidly.

Mercury from Dental Restorations in Cremations

Most of the data of estimates of the amount of mercury in dentant restorations are from the 1990s or before, with detailed studies done in Switzerland in 1990 and 1995. The most specific estimate was done in 2010 by Bender for a US Congressional hearing.

Bender estimates that mercury emissions from crematoria will be about 7,700 kilograms (17,000 pounds) in 2020. This estimate is based on a cremation rate of 50%, making an interpolation of estimates from the Cremation Association of North America and estimates of tooth retention and amalgam per cremation as noted by studies in the UK. This estimate compares to a mercury flow model from the US EPA of 2005-2010 emissions of about 3,000 kg (6,500 pounds).

Cain, et al, and Cain, 2006, of the US EPA Region V, estimated mercury emissions from crematoria at about 3 metric tons a year, with the split between air and land emissions for 2005-2010 being 2.2 and 0.74 tonnes, respectively.

In a 1993 Swedish report (Axelsson) on mercury flows in Göteborg (Gothenburg), an accounting was done for cremations in 1984 and 1991, with a forecast for 2000.

The study notes that the amount of mercury in fillings per cremation changed from 1984 and 1991 from 3.6 to 4.6 grams, while the forecast is for 5.9 grams in 2000. This is due in part to a change in the age distribution of the deceased, but more due to an increased retention of teeth by older people and hence a greater presence of mercury fillings in the cremations. For example, from 1984 to 1991, the percent of cremations and amount of mercury per cremation changed as follows in Gothenburg;

Mercury from Dental Fillings in Cremations in Gothenburg, Sweden

Age Group	Mercury per cremation, grams	Mercury per cremation, grams	Percent of cremations	Percent of cremations
	1984	1991	1984	1991
0-4	0	0	1%	1%
5-29	10	5	2%	1%
30-34	18	10	1%	1%
35-39	17	10	1%	1%
40-44	15	10	1%	1%
45-49	13	13	2%	2%
50-54	12	12	3%	2%
55-59	8	12	4%	3%
60-64	6	8	7%	5%
75-84	2	3	23%	21%
85+	1	2	33%	36%

For Switzerland, two articles from a Swiss dental medicine magazine were found on a determination of mercury levels in the teeth of deceased who are cremated.

The first Swiss article is from a 1990 journal of dental medicine (Rivola). A study was done of the amount of mercury found in 130 cremations in Zurich, with each body examined by visual techniques and x-rays. Based on a study of the amount of mercury in extracted teeth (62 molars and 72 pre-molars), it was assumed for the cremations that each molar filling had 1.20 grams of amalgam, while each pre-molar filling had 0.79 grams of amalgam. The authors assumed that 40% of the amalgam was mercury, although noted that a more recent study had found that 43% of the amalgam was mercury.

The average age of the deceased was 77.4 years, and it was found that 32% of the deceased had no natural teeth, with a 95% confidence interval of $\pm$ 8.3%. For those with teeth (average age was 60.9 years), there were 2.49 grams of mercury in the fillings, with a 95% confidence interval of $\pm$0.37 grams.

The second article is from 1995 (Matter-Grütter) and builds on the first article. The amount of mercury in 28 cremations was studied and given by age, but it is not clear if these are representative of the Swiss population as a whole or instead more likely, it is what was available as part of the study to determine mercury emissions from crematoria. The statistical analyses of these data were performed by this reviewer. The results are as follows:

Mercury from Dental Fillings in Test Cremations in Zurich, Switzerland

Age	Number	Average Mercury, grams	Standard Deviation, grams	Coefficient of Variation
20-40	5	4.08	1.84	45%
41-60	7	4.45	1.32	30%
61-80	8	2.94	2.20	75%
81-99	8	2.32	1.73	75%

In a 2003 report from the United Kingdom agency Defra (Department for Environment, Food and Rural Affairs), it was estimated that the amount of mercury from cremations will increase in that country by two-thirds from 2000 to 2020 and account for between 11% and 35% of all mercury emissions to the air in 2020. After 2020, the amount of mercury from cremations is estimated to stabilize for a period of time and then decrease, based on the declining amount of mercury in current and future dental restorations.

The 2003 Defra report includes data on the occurrence of restorations in various age groups, developed by the Office of National Statistics, in a 1999 document. In one table, it provides the following data for the percentage of adults with no teeth:

Percentage of Adults in the UK with no teeth
Office of National Statistics, 1999

Age	1978	1988	1998
16-24	ND	ND	ND
25-34	4	1	ND
35-44	13	4	1
45-54	32	17	6
55-64	56	37	20
65-74	79	57	36
over 75	79	80	58

Also provided are data for the number of restorations in those adults who had teeth:

Number of Sound Restorations in Dentate Adults in the UK
Office of National Statistics, 1999

Age	1978	1988	1998
16-24	8	5.5	2.9
25-34	9.8	10	7.4
35-44	8.9	11.1	10.1
45-54	7.1	9.6	11.1
55-64	ND	7.1	9
65-74	4.8	5.7	8.2
over 75	ND	3.7	6.5

The report noted that in a 2001 study of 18 cremations in the UK, six released very little mercury, with the average mercury emission being 0.9 grams, with a maximum of 6.76 grams. The report further notes that in the UK, 3.0 grams of mercury per cremation is typically used in calculating mercury emissions from cremations and is used in the National Atmospheric Emission Inventory. The 2004 Defra consultation recommends that this number be revised and more details are given in the next section.

Air emissions from cremations

Data on mercury air emissions from cremations were found from the UK, the US, Norway, Sweden, Finland and Switzerland. The range of data is very large, from 0.94×10^{-3} gram/body in a US report to 8.6 grams in other reports. Defra (2004a) reports ranges as high as 6.76 grams from some cadavers. In no case was a mass balance performed, with measurements of mercury deposited on the walls of the crematoria or the amount of

mercury in the cremated ash, the filter or water from scrubbers. While one study found a relationship to account for almost 77% of the mercury from the cremation of three cases of mercury amalgam added to a coffin without a corpse, other reports account for less than 1% of the mercury available in the fillings.

A 1990 correspondence by Mills in *Nature* noted that there had been few, if any, studies on the release of mercury from crematoria. In laboratory work, the author found that decomposition of amalgam was detectable at 200º C and essentially complete at 700º C. The author concludes that during cremation, all the mercury in standard dental amalgams would be released.

Other researchers concluded that higher temperatures are needed for the release of all mercury from amalgam. Odanovic and Djurdjevic concluded that decomposition was very significant for in a laboratory test of heating amalgam to 400º C, with the percentage of mercury in the amalgam falling from 50.17% to 3.11% after two hours of heating. At higher temperatures, the release of mercury was more complete; a temperature of 800º C left mercury amounts at 0.7 % after 1.5 hours, while mercury was below detectable levels after heating to 850º C for one hour or more.

Mills estimates that 30% of the adults in the UK have lost all of their normal teeth and that the rest have an average of 7.5 filings. He concludes that the average amount of mercury in the deceased is 5 fillings, and, by measuring the amount of mercury in ampoules, estimates an average of 3 grams per cremation.

The estimate of Mills is judged to be reasonable by a follow-up correspondence in *Nature* by Künzler and Andrée, who report on tests done in a crematorium in Switzerland, but is said to be too high by Basu and Wilson in their follow-up correspondence in *Nature* in 1991. Using data on the age distribution of the death records and the loss of teeth by age group, their estimate is that the following amounts of mercury would be present in the deceased:

Estimated Mercury in the fillings of the deceased in England and Wales, 1988
Basu and Wilson

Age group	Number of deceased	Percent with teeth	Number with teeth	Number of fillings	Grams of mercury, at 0.6 grams per filling
under 65	161,587	100%	161,587	9	872,570
65-74	137,179	43%	59,000	5.7	201,780
75 and older	272,642	20%	54,500	3.7	120,990
Total	571,408	-	-	-	1,195,340

Basu and Wilson estimate that that the estimates of Mills are too high, but as noted by Burton, there is a mathematical error in their article. According to the data in the table above, taken from Basu and Wilson but corrected by this reviewer to conform to the note by Wilson, the average mercury per cremation would be about 2.1 grams.

As noted in the previous section, the 2003 and 2004 consultations of Defra note that the UK National Atmospheric Emission Inventory for 2002 uses a value of 3 grams per cremation, and that it is estimated that cremations account for about 16% of all atmospheric emissions of mercury in the country. Both reports point out that tests done in the UK of 18 cremations found emissions averaging 0.9 grams per body (with the highest test at 6.76 grams), and the 2004 consultation includes a description of the work of both Mills as well as Basu

and Wilson, and Burton, as described above. Recognizing that developing an estimate is a difficult process, the consultation looks at the changes in the number of teeth remaining at various ages and the number of restorations in the various age groups, and develops an alternative estimate, as follows:

Estimated Mercury Emissions from Cremations in the UK
(2004 Defra Consultation)

Year	Emission (grams/cremation)
1968	0.49
1978	0.66
1988	1.04
1998	1.71
2003	1.92

For the US, the data on mercury emissions from crematoria is extremely limited. Two different EPA reports on the Internet from 1997 provide two drastically different conclusions, both based apparently on the same study.

For the US, in one study (EPA, 1997a), a value of 1.5×10^{-3} kg (1.5 grams) of mercury per cremation is reported, from a 1992 test done in California of a propane fired crematorium. The EPA report does not provide data on the age of the deceased, or the number and size of the fillings and the mercury estimated to be contained in the fillings. The reference for this data is a report of California Air Resources Board (CARB), 1992. *Evaluation Test on Two Propane-Fired Crematories at Camellia Memorial Lawn Cemetery. Test Report No. C-90-004. October 29, 1992*. This reviewer has not been able to obtain this study.

In the second EPA report (1997b), the amount of mercury is reported at 0.94×10^{-6} kg/body (0.94×10^{-3} gram/body). The test results were said to have been obtained from a confidential test report to the California Air Resource Board. The reference given for this report is *FIRE Version 5.0*, EPA-454/R-95-012, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, August 1995.

Both EPA reports note that "Only one set of data are available for the average quantity of mercury emitted for a cremation" in the U.S. (Page A-17 in EPA, 1997a, and page 4-36, EPA, 1997b.)

Two years later, however, other data were available, and for the US estimate of mercury releases from cremation, the US 1999 National Emissions Inventory uses data from a study done at the Woodlawn Cemetery crematorium to estimate that there are about 5.32×10^{-3} lbs of mercury emitted to the air per ton of cadavers cremated, with an average cadaver estimated to weigh 168 pounds (ERG). This is equivalent to 0.2027 grams per cremation.

In 1999, EPA and the Cremation Association of North America did a series of tests of emissions from cremations at the Woodlawn Cemetery, located in The Bronx, New York, where the tests were done from June 11 through June 17, 1999. The data are both reported on the Internet, and, according to an email note from a staff person with the state of Maine (Macdonald), in an industry trade magazine, *The Cremationist of North America* (Vol. 35, No. 4, 1999). In addition a review was done of the actual study, which was obtained from the US EPA.

Nine cremations were done, 3 each at the operating temperatures of 1400° F (760° C), 1600° F (870° C) and 1800° F (980° C).. The article on the Internet says that mercury averaged 0.23 grams/hour of operation, but

there are no data on mercury emissions varying with temperatures, since, according to the article, it was assumed that mercury emissions would not change with temperature. According to the writer from Maine, this level of emissions appears to be in the range of 1 gram or so per cremation. This would imply that each cremation lasts over 4 hours, much longer than what is reported in European information.

However, the actual study (US EPA, 1999) shows somewhat different data. For background, the crematorium has four cremation units that feed into a common chimney, which includes a wet scrubber. According to Rahill (2005b), this is the only crematorium in the US that is known to have a wet scrubber and was specifically selected for this test to determine the effectiveness of a scrubber to remove materials from the exhaust gas. Each cremation unit has two chambers, the primary or retort chamber and the secondary chamber. The retort is preheated prior to introducing the body container for cremation. A typical cremation lasts approximately two hours. Following the cremation, the cool down, removal of the remains, and preheating for the next cremation takes approximately one hour.

As noted above, testing was conducted for three conditions, where secondary chamber temperatures were varied to be about 1400º, 1600º and 1800º F per test (approximately 760º, 870º, and 980º C, respectively). Each test consisted of three sampling runs at the scrubber inlet and outlet.

The data for these tests are contained in the following table:

Woodlawn Cemetery Cremation Test Results for Mercury, 1999

Run	Age	Gender	Weight	Container Weight	Body wrappings	Average Secondary Chamber Temperature. ºF	Inlet Hg emissions, g/hour	Outlet Hg emissions, g/hour
1	78	M	157	15	No clothes; plastic sheet	1425	0.3	0.2
2	70	F	163	85	No clothes; plastic sheet	1475	0.003	0.006
3	91	M	182	10	Plastic pouch	1450	0.51	0.23
4	55	M	199	10	Plastic pouch	1660	0.82	0.71
5	74	M	180	100	Suit, leather shoes	1656	0.14	0.07
6	76	M	188	30	Plastic sheets	1645	0.02	0.01
7	65	M	140	100	Hospital gown	1845	0.24	0.16
8	88	F	200	10	Plastic pouch	1838	0.014	0.012
9	88	M	105	10	Plastic pouch	1838	0.005	0.007
Average	76.1	7 M, 2 F	168.2	41.1	-	-	0.228	0.156

The report gives no data on the number of teeth nor the number of restorations present. In addition, although it is clear that some mercury was removed by the wet scrubber system, no data are provided on the analysis of the mercury in the water from the scrubber. The ash also does not appear to have been tested for mercury. The report also does not indicate how the cadavers for analysis were selected and whether they are representative of the population being cremated. For example, as seen by the data, there is not a balance between male and female cadavers. According to the Defra second consultation (2004a), elderly men are likely to have more fillings than elderly women, so the above tests may overstate the amount of mercury from cremations.

The tests for mercury releases also were not done continuously during the cremations. In the nine test runs, gaps in emission testing at the inlet to the scrubber range up to 40 minutes. The clock times between the start and the finish of the test ranges from 2 hours and 13 minutes to 2 hours and 40 minutes.

The number of tests are too few to determine if there is a correlation between secondary chamber temperatures and mercury emissions, and a cursory review does not indicate that such a correlation exists, with mercury emissions at the input to the scrubber averaging 0.27 grams per hour for the tests at about 1400º F, 0.33 grams/hour for the tests at 1600º F and 0.086 grams per hour for the tests at 1800º F. (On the other hand, there were increased emissions of HCl, Cd, Pb and PCDD/PCDF homologues with increased temperatures.)

The Woodlawn study only reports the emissions in terms of grams per hour and no conversion is given for total releases. According to Rahill (2005c), most of the mercury emissions would have been during the first hour of actual cremation, and the values reported are for that period. He concludes that the reported values of emissions per hour are equivalent to total emissions. Thus, for run 1, he concludes that the total emissions at the inlet to the scrubber were 0.30 grams of mercury.

The authors of the Woodlawn study, however, recommend against the use of their data without caution; all three volumes of the EPA study contain a disclaimer that:

> "This report presents the results of a single test program at a single cremation facility. It should not be assumed that these results would characterize emissions at other cremation facilities without further study."

Moreover, the lead staff person (Surman) for the consulting firm (Midwest Research Institute) that performed the work notes that the data are subject to interpretation. He goes on to note that the data are averages and recommends that they be multiplied by the total time of the cremation. He also notes that they do not include measurements from the time break during which the measuring instruments were switched from one access port to another, nor any releases from the warm-up and cool down periods. For run 1, he recommends multiplying the emissions per hour times the difference between the end and the start of the test, or with a start time of 15:21, and an end time of 18:01 (total time lapse of 2.67 hours), the total emission would be 2.67 hours x 0.30 grams/hour or an estimated 0.8 grams of mercury for this cremation.

Thus, there is a significant difference of opinion among two of the principals in the Woodlawn study on how to interpret the data from this study. In addition, the EPA project manager of the study (Curtis) questions the validity of the testing, and notes that mercury levels were sometimes higher after pollution control equipment than before it (Cain, 2005).

As another estimate of mercury emissions from US crematoria, an email note from a state official in Maine (Macdonald) noted that a report titled *The Northeast States and Eastern Canadian Provinces Mercury Study*, February, 1998 suggests a range of emission values from 0.8 to 5.6 grams of mercury per cremation, or an average rate of 2.9 grams of mercury per cremation. A copy of this report has not been obtained by this reviewer. However, a chapter of this report was found on the Internet, and in this chapter, the suggested emission levels from crematoria are based on a review of data by EPA from Germany, Switzerland and the United Kingdom is said to be about 1 gram per cremation. In addition, a more recent NESCAUM report, *Inventory of Anthropogenic Mercury Emissions in the Northeast*, reports the same range of estimates from six cited references.

A more recent US estimate of mercury emissions from crematoria is from a mercury flow workbook prepared for EPA Region V by Barr Engineering and updated by EPA staff. In the January 2006 version (Cain, 2006), the estimate is that in 2005, there were 2,961 kilograms of dental mercury that were in the corpses cremated, and

75% (2,221 kg) were released as air emissions and 25% (740 kg) were released to the land (also, US EPA, 2010). The primary source of the land emissions is mercury attached to settled particulates from the crematoria. This estimate is based on the judgment of staff from the Wisconsin Department of Natural Resources, which helped develop the data for the model – no hard data were available for this estimate.

In a Canadian publication, a January 1998 document known as the *Emission Inventory Guidebook*, the role of crematoria for a variety of air emissions is summarized, with a review of data from 12 countries. It concludes that for most materials, crematoria are a minor source of emissions. The exception is heavy metals, including mercury, for which cremations are said to be responsible for up to 21% of the emissions, as in Sweden.

The guidebook notes that the majority of the mercury comes from dental fillings, which it lists as being between 5 and 10 grams per corpse. However, it lists the emissions from the EPA study as 9.344×10^{-7} kg per body, or 9.344×10^{-4} grams/body, less than 0.02% of the mercury contained in the fillings.

In a February, 2001 newspaper article in a UK newspaper, it was report that the 440,000 cremations done annually in Great Britain resulted in an emission of 1,300 kg of mercury to the air, or about 2.95 grams of mercury per cremation. As noted previously, a 2003 UK report estimates that the amount of mercury from cremations in that country will increase by two-thirds from 2000 to 2020 and in 2020, cremations will account for between 11% and 35% of all mercury emitted to the air.

In Norway, a researcher reported in a February 2001 email that it is estimated that between 2 and 4 grams of mercury are emitted to the air per cremation, but that it is dependent on the age of the deceased. He has measured one such cremation and found an emission level of 0.80 mg Hg/ Nm^3 gas over a cremation of 2 hours. The gas volume was some 3,500 Nm^3 gas/hr.(one furnace), so the total volume was 5.6 grams. In a different email, this same researcher reported for another cremation the same concentration of mercury, but a 1.5 hour duration and a gas volume of 3,880 Nm^3/hour.

A staff person at the Norwegian equivalent of the EPA also wrote an email, noting that an inventory of mercury emissions in Norway puts the emissions per cremation at 4.9 grams. The report is available on the Internet at http://www.ssb.no/milgiftn/.

In a draft fact sheet on crematoria from early 2001 being prepared for the Swedish Environmental Protection Agency, an average emission of 5 grams of mercury is assumed. The reference for this assumption is not listed, although the bibliography for the fact sheet has several references to a number of Swedish reports on mercury emissions from crematoria. The fact sheet notes that in Sweden, cremations account for just under 32% of the mercury emissions to the atmosphere.

Research in Switzerland was published in 1995 in an article in a Swiss journal of dental medicine (Matter-Grütter, "Quecksilber- Emissionsmessungen in einem Krematorium"). In this study, the amount of mercury was estimated in 54 bodies before cremation using a modification of the technique in the article described above, by classifying the filings in various size categories as well as type of tooth. The bodies were cremated without the level of mercury known to the people doing the cremations or testing the stack for emissions and the exhaust gases were measured for mercury levels. Data on the deceased include their age in 20 year intervals and the amount of mercury in their fillings and the results are provided for each cremation and analyzed by output vs. input and by furnace temperature.

A total of 60 cremations were done, divided into a group of 54 cremations of corpses, approximately half with mercury fillings and half without, and 6 "blind" tests where the coffins were empty but a specific amount of mercury amalgam was added in three of these coffins.

There was a correlation of 0.85 between input quantities of mercury and output quantities when all data were included and 0.93 when several "outliers" where excluded. However, the output averaged only about 56% of the input for the 54 cremations of actual bodies and approximately 77% in the three tests that a known amount of mercury amalgam was added to the blind test coffins. There was also mercury in the emissions of corpses that had no fillings. In a series of cremations of corpses with no fillings, the level of mercury emissions in the exhaust steadily declined with each subsequent cremation. It was concluded that during those cremations with mercury fillings , some of the mercury was deposited on the walls of the crematory rather than being exhausted to the air. The wall-deposited mercury was then emitted during subsequent cremations, including cremations that had no mercury. An analysis was also done of mercury emissions from the cremation those corpses without mercury fillings with respect to exhaust temperatures. A positive relationship was found, with more mercury emitted with higher temperatures, and a correlation of 0.56. There was no correlation found for mercury emissions and age for those corpses that had no fillings.

Actual output data were not provided in a numerical form, but instead are represented in a bar graph, with the highest value being approximately 8.6 grams, as measured by this reviewer. Similarly, the level of mercury emissions per Nm^3 was not provided, although it was stated that in 82% of the cremations of people with fillings, emission levels exceeded 0.2 mg/Nm^3. In addition, this level was exceeded for 12% of the cremations of bodies with no fillings.

It was recognized that mercury could come from other sources, such as mercury in body tissues or other devices, such as the batteries of pacemakers. However, these sources of mercury were not calculated or estimated.

Rahill (2008) describes both the Woodlawn study noted above and studies done in the UK in which he writes that the emissions were 0.128 grams per cremation from a test at the Craigton Crematorium in 2006 and 0.323 grams per cremation at the Linn Crematorium in 2007. No citations were provided for obtaining the reports from these two studies, and this reviewer was unable to find any reports for these data on the Internet. A note was sent to Mr. Rahill in March 2012 for either copies of the reports or links on the Internet.

In 2010 article, Carns, et. al., reported on the results of mercury emissions from four UK crematoria using atomic spectrometry. They note that they were unable to calculate the total quantity of mercury from each cremation because they did not collect data on the flow rates, but that all the mercury appeared to be emitted within the first 40 minutes of the beginning of the cremation process. They also noted that the ratio of ionic mercury to total mercury decreased with increasing concentrations of mercury. For example, 75% of the total mecury was oxidized in the test where the mean total mercury gas concentration was 25.8 $\mu g/m^3$, and 29% where the total mean gas concentrationw as 1094.5 $\mu g/m^3$.

Mercury Emissions and Crematoria Workers

The issue of the impact of the mercury on the workers at crematoria has been discussed in varying depths by researchers in at least Sweden, Norway and the UK.

In 1994, an article by von Platen in a Swedish newsletter on worker protection postulated that the gaseous mercury produced during a cremation would disperse through the porous brick of the oven and that the levels of mercury could reach 370 times the Swedish standard for mercury in the air of a work environment. This theory was challenged by a later writer (Stråby), although no actual air measurements were offered by either writer.

A year later, the Swedish Institutet för vatten och luftvårdsforskning (Institute for Water and Air Protection Research) in Göteborg prepared a report on mercury in crematoria, which was referenced in a similar report done by the Norwegian Statens arbeidsmiljøinstitutt (The State Work Environment Institute). According to the

Norwegian report (Haugen), the Swedish study found average values of mercury of 0.122, 0.011, 0.177 and 0.249 µg/m^3 in the air at four crematoria. The outside air had average levels of mercury of 0.002 µg/m^3.

In the Norwegian study, measurements were made at three crematoria for a period of one week each. With one exception, all measurements in the air were below the level of detection, which, depending on background levels was 0.2 to 2 µg/m^3. The level of mercury in the morning urine of 29 crematoria employees from 18 crematoria was measured and found to be an average of 15.2 nmol/liter, with a range of 4-39 nmol/liter. According to the authors, any concentration of less than 50 nmol/liters is assumed to be non-work related. The workers who were tested worked more than 50% time and the crematoria all had a minimum of 100 cremations a year.

A more detailed analysis of the impact of the mercury released during cremation on the mercury levels in the employees of the crematoria was presented in an article in *The Lancet*, published in 1998 (Maloney), with the research done in the UK. Measurements were made of the level of mercury in the worker's hair, stratified by the type of work that they did, along with data from a control group and the number of fillings in the people studied. The authors conclude that the employees had an increased level of mercury in their hair as compared to the control group ($p = 0.0016$) and that there were statistically significant differences between the strata for the types of work that people did ($p = 0.024$), as shown in the following table.

Mercury in Crematoria Workers
The Lancet, 1998

Occupation	Number sampled	Mean Hg in hair in ppm, and standard error	Mean number of fillings
Administration	38	1.84 (0.20)	6.84
Cremation operative	48	1.60 (0.25)	5.85
Groundskeeper	11	1.47 (0.59)	4.82
Total crematoria workers	97	1.68 (0.16)	6.12
Control	46	0.97 (0.11)	5.65

The research did not show a statistical correlation between the number of cremations performed annually and the levels of mercury found, but there was a statistically significant different ($p = 0.039$) between those workers at crematoria with more than 1,600 cremations a year and those workers at crematoria with low outputs, with means of 1.96 and 1.47 ppm, respectively.

A follow up exchange in *The Lancet* (Nielsen) expressed some questions about the conclusions of the authors that the levels of mercury in the crematoria employees' hair was related to their work in the crematoria and instead pointed out a possible correlation with the number of dental fillings of the workers and the potential of other factors, such as the consumption of fish. The authors of the original article said that further analysis of the data showed only a superficial explanation of the levels in the hair and number of fillings and believe that the level of fish consumption in the UK would not warrant the levels of mercury in the hair.

Mercury Emissions and the Neighboring Area

Dummer, et al, found that there was an increased risk of stillbirths around crematoria in Cumbria, England during the period of 1956-1993, but the cause of this increase was not identified, and the authors call for more investigations.

The Level of Mercury in the Air Surrounding Crematoria

In a March 2012 report for a proposed crematorium in Manassas, VA, Green and Zemba estimated the mercury levels that would be found in the air surrounding the crematorium based on an estimate of cremating 4 corpses a day with an average of 3 grams of mercury per corpse. They estimated that the mercury levels would be 3 ng/m^3 in a nearby residential area and concluded that this level would be safe as they were far lower than the existing health-based exposure guidelines for the general public, which range from 300 ng/ m^3 from the US EPA to 100 ng/ m^3 from the Virginia DEQ. The report does not given the assumptions of stack height or local conditions, nor the distance to the neighborhood or the school. This reviewer contacted the authors and in a telephone conversation, the authors said that they would provide the reviewer with more information to include in this report.

In a draft document from June, 2011, Craft looked at four issues related to mercury emissions from crematoria:

1. emission estimates
2. dispersion modeling results
3. acute risk calculations, and a
4. partial effort to identify risk reduction measures.

For the actual risk calculations, scenarios were examined at 20 meters and 300 meters from a hypothetical crematorium. At 20 meters, assuming a constant emission rate of 0.006 grams per second, a Hazard Index of 30 was calculated under the standards of the California Office of Environmental Health Hazard Assessment (OEHHA), while at 300 meters, a Hazard Index of 2.7 was calculated.

The California Office of Environmental Health Hazard Assessment (OEHHA) maintains of web page of acute, 8-hour and chronic reference exposure levels. As of December, 2008, the values for mercury and inorganic mercury were 0.6 µg/m^3 for acute, 0.06 µg/m^3 for 8-hour and 0.03 µg/m^3 for inhalation chronic reference exposure levels and 0.16 µg/kg body weight-day for a chronic oral reference exposure level.

A 2006 study done of a crematorium in Rawlins, Wyoming (URS) looked at 20 species of emissions from the stack, and an air dispersion model was developed using the Industrial Source Complex Short Term, Version 3 model (ISCST3). A stack height of 15 feet was used, along with natural gas as a fuel. Two mercury emission rates were found in the literature, one at 1.438 x 10^{-6} lb/hr from a 1996 EPA report and the other at 5.73 x 10^{-4} lb/hr from the EPA/CANA test at Woodlawn in 1999. A maximum emission rate of 5.732 x 10^{-4} lb/hr was assumed and calculated to be equal to 7.222 x 10^{-5} grams per second. Using these assumptions and values, the annual average mercury concentration was estimated at 8.06 x 10^{-3} µg/m^3, with 1 hour concentrations of 0.246 µg/m^3. These values were below the then-existing US EPA Region 9 Annual Preliminary Remediation Goal of 0.31 µg/m^3. According to the study, only cadmium and dioxins/furans were estimated to exceed air quality standards.

An email note was sent to the URS Corporation in November 2011 to see if the results of the model might be scalable given changes in estimates of the quantity of mercury from cremations with more recent data as well as future estimates. The short answer (Bloom) that they could be if the number and speciation is not too different from the original data. The full answer provides other insights and suggestions for this topic and so is reprinted here in its entirety:

I have been asked to respond to your questions regarding Hg emissions from crematoria. The good news is that I know quite a bit about the behaviour of mercury released to the environment, but the bad news is that I do not know so much about atmospheric dispersion modeling. That having been established, I believe that the results would be scalable over a reasonable range of Hg concentrations as long as several criteria are met: (1) the speciation ratios of gaseous Hg(0) to gaseous Hg(II) to particulate Hg in the emissions scenarios are always the same, regardless of total Hg concentration. This is critical, as the deposition rates for particulate Hg and gaseous Hg(II) are orders of magnitude greater than for gaseous Hg(0), leading these to fall out much closer to the source. Because of the nature of the chemistry of cremation, it is likely that the vast majority of Hg emitted from crematoria is in the form of Hg(0), making this concern unlikely to be of major effect; (2) one must assume that the concentration of Hg in the flue gas emissions are low enough in all scenarios that one does not risk seeing condensation of gas phase Hg(0) to liquid phase Hg(0) droplets in the case of higher flue gas concentrations, upon coming into contact with cooler outside air. If one was burning bodies that contained no dental amalgams (average Hg concentration <0.1 mg/kg, or 5-10 mg Hg/body), the levels of emitted mercury should be very low, and even if two or three times higher, the levels would still be low, making condensation, even on very cold days seemingly unlikely (air at 20 C can hold around 13.2 mg/m3 of Hg(0) at saturation, while at 0 C, the saturation level is perhaps more on the order of 2.4 mg/m3). If the body contained a mouth full of dental amalgams, on the other hand, then the amount of Hg emitted could be up to 20 grams of Hg, which would likely be volatilized as a relatively short spike into not too large a volume of flue gas. For example, 20 grams of Hg(0) released into 1000 m3 of fluegas would give a level of 20 mg/m3 (at STP), which would definitely risk precipitating out micro-droplets of liquid Hg if rapidly cooled to 0 C. Of course, if the released flue gas was diluted by outside air at a rate faster than it is cooled down, then the Hg(0) might always remain in the gas phase. However, watching steam condense from combustion stacks on cold days suggests that condensation and so rapid fallout would be a possibility. Finally (3) there is the issue of active uptake of gaseous Hg(0) by plant leaves--this is a non-linear relationship, with leaves actually emitting Hg(0) from their leaves (taken up from groundwater) when the air levels are low (< 3-5 ng/m3 of Hg(0)), a net uptake/release balance of zero at this concentration (the compensation point), followed by active uptake of Hg(0) and deposition of the then enzymatically oxidized aqueous Hg(II) into the forming wood of the tree when atmospheric levels reach levels of greater than the compensation point. The exact compensation point varies with foliage, Hg(0) concentration in the ground water near the roots, and likely with season and time of day. My guess is that given the short stacks found on crematoria, and the likely significantly higher than 5 ng/m3 emissions levels of Hg(0), that uptake by local foliage is a significant loss factor. This has been shown in the vicinity of mercury cell chlor alkali plants, municipal waste incinerators, alumina extraction plants, gold mines, etc. In fact, one can possibly develop empirical factors by which the biochronologies of Hg bound into wood tissues versus year of deposition (by counting tree rings) which could be used to validate results from dispersion modeling--especially historically and over a wide area. For example, if more bodies with more amalgam fillings were combusted in the 1970's than in the 2000's, then this would be seen as a peak of Hg trapped in wood cores drilled from local trees. I have done quite a bit of this kind of work together with my colleague, Dr. Ralph Turner, formerly of the Oak Ridge National Laboratory--although there are a range of considerations that tends to render the methodology more qualitative (a good comparison between relative exposures at different sites and times) than quantitative, since it is near impossible to obtain specific uptake rates for specific tree species (we have a small amount of such data from trees in Oak Ridge, TN).

In 2011, two reports were done by the consulting firm EnSafe for the City of Spring Hill, TN on the estimated air emissions from a proposed crematory. In the first report, a description was given of 16 types and categories of air pollution, with the note that most attention focused on dioxins/furans and mercury. The report looked at 11 pollutants and compared expected emissions from the crematory with those from other sources, such as

residential natural gas furnaces, residential fireplaces and wood stoves and commercial/institutional boilers fired with natural gas or wood. The source of the data is the EPA FIRE Database, and mercury emissions are put at 0.001 lbs per cremation or about 0.45 grams per cremation. The report concludes that emissions are dioxins/furan emissions would be roughly three orders of magnitude lower than those from a residential woodstove and that mercury emissions would be on the order of magnitude of a commercial/institutional boiler fired either by natural gas or wood.

In the second report, EPA's air dispersal model AERMOD, version 11103, was used to predict air concentrations. This report provides data on mercury, dioxins and furans; for mercury, 19 estimates are provided for long-term emissions rates, 1-hour rates and 8-hour rates. As an example, 1-hour rates vary from 2.61×10^{-6} to 2.39×10^{-3} grams/second. The emission rates used were:

1-hour:	US EPA 4.15×10^{-4} g/s and a maximum of 2.39×10^{-3} g/s
8-hour:	US EPA 1.55×10^{-4} g/s and a maximum of 8.96×10^{-4} g/s
Annual:	US EPA 1.38×10^{-4} g/s and a maximum of 7.96×10^{-4} g/s

A stack height of 29 feet was used, and the California OEHHA screening levels were used at 0.6 $\mu g/m^3$ for 1-hour acute, 0.06 $\mu g/m^3$ for 8-hour acute and 0.03 $\mu g/m^3$ for annual chronic exposures. For the entire modeling domain, mercury emissions were estimated to exceed the screening level in two of the six rates – the maximum emission rate for 1-hour acute exposures and the maximum emission rate for 8-hour acute exposures. In the other four analyses, the mercury levels were between 17% and 87% of the screening level.

The dispersion of mercury which is released from crematoria might partially be indicated by studies that look at the dispersion of mercury from solid waste incineration systems. In a review of mercury from incineration by van Velzen, et. al., (2002), it is noted that flue gas leaving an incinerator stack has a linear velocity of more than 10 meters per second, and will act as a free turbulent jet, resulting in considerable dilution in a short period of time, with a dilution factor of 10^5 after about 200 meters and 10^6 after a distance of 1 kilometer.

Mercury in the Soil Surrounding Crematoria

In an anonymously authored 1990 article published in *Resurgam*, the newsletter of the Cremation Society of Great Britain and the Federation of British Cremation Authorities, results are reported from soil samples at a crematorium that had done in excess of 112,000 cremations over a period of 40 years, as given in the table:

Mercury in Soil Surrounding a Crematorium
Great Britain

Sample number	Distance from chimney	Mercury (mg/kg)
9H005P	142 meters, upwind	0.09
9H004P	61 meters, upwind	0.10
9H003P	51 meters, downwind	0.17
9H002P	138 meters, downwind	0.17
9H001P	233 meters, downwind	0.09

In a 1992 article in a dental magazine in Denmark by Arenholt-Bindslev, the author says that some studies have found slightly elevated mercury levels in the soil and plants near crematoria, whereas other studies have not found elevated levels. The reference cited is an 1986 Swedish report by S. Mörner and T. Nilsson,

"Kviksilverutläpp från Göteborgs krematorier", published by the city of Göteborg. This reviewer has not yet been able to obtain a copy of the Göteborg study.

A 1994 study by Phillips, et. al., in the UK found that mercury levels in the soil were elevated around several crematoria. In one case, the soil levels were from 610 to 1,320 ppb, compared to a background or control level of 430 ppb. The highest level was found in the location closest to the chimney. Samples consisted of 2 kg of soil from underneath the top 2 cm of soil, but the depth of the samples was not described. No data were provided on the number of cremations at this crematorium, nor the length of time that it was in operation.

In a 1996 Swiss article (Anon., "Schwermetalle und Fluor in der Umgebung der Zürcher Krematorien"), there is a discussion from a study that was made of mercury and other substances in the area surrounding several crematoria in Zurich. It was found that there were measurably higher levels of mercury in the soil than in background soil, especially within 100 meters of the crematoria, although the report did not provide the actual data, nor information on the number of cremations performed nor the length of time that the crematoria had been in operation. While the current levels of mercury in the soil were not found to be of environmental or health concern, the future level of mercury in the soil is of concern, since the number of cremations is expected to increase faster than the decrease in the amount of mercury used for dental purposes. Three scenarios where done of mercury emissions from crematoria over the next 50 years, using assumptions of 2, 3 and 5 grams of emission per cremation.

In a latter article from Switzerland (Schilling), it was noted that the soil near the Winterthur crematorium near Zurich, there were elevated levels of mercury to a distance of 500 meters in a 1992 study. However, no specific data were provided in this article. Because of increases in the number of cremations at this location, the leader of the canton's soil protection unit [Fachstelle für Bodenschutz] forecast a significant increase in the contamination of the soil. However, no more recent soil tests have been done of the mercury levels near the Zurich crematoria since the 1992 study at the time that this article was published. .

In a 1997 New Zealand study (Nieschmidt and Kim), an investigation was done of the soil surround three crematoria, and increases were found of mercury level levels in the top 5 cm of soil. A summary of the data can be found in the next table:

Some Results of Soil Studies around Three New Zealand Crematoria, Published 1997

Crematoria	Year opened	Years of operation	Total cremations	Background concentration (ppb)	Maximum concentration (ppb)	Geometric Mean above Background
Purewa	1957	37	66,200	140	870	350
Hamilton	1964	30	28,800	200	560	170
South Auckland	1982	12	800	90	120	25

For both the Purewa and the Hamilton crematoria, the authors found that mercury concentrations increased as the distance from the crematoria increased, reached a peak, and then decreased. For the Hamilton crematorium, the peak was found at a distance of 15 meters from the chimney.

In addition, at both the Purewa and the Hamilton crematoria, the authors also provide data from samples extracted from deeper levels. At the Purewa crematorium, at the site where the mercury concentration in the 0-5 cm level was 850 ppb, it decreased to 130 ppb in the 5-15 cm depth and 90 ppb at the 15-30 cm level. At the Hamilton crematorium, a site with 410 ppb mercury in the 0-5 cm level had 170 ppb mercury in the 5-15 cm

interval and 120 ppb in the 15-30 cm. As can be seen, the levels of mercury in the depths under 5 cm were below background levels for both crematoria.

While the authors estimate that there is an increase of 100 ppb of mercury in soil concentrations for every 18,000 cremations, they also estimate that most mercury (99.95%) either never reaches the local soil or is deposited and then re-volatized.

In a 2002 article looking at the levels of 32 metals in the topsoil of Oslo, Norway, taking 300 samples at 1 km intervals (Tijhuis, et. al.), the researchers found mercury levels ranging up to 2.30 mg/kg, with a mean of 0.13 mg/kg and a median of 0.06 mg/kg. The highest median values were found in central Oslo, with levels 8 times those of the median of the entire city. Using factor analysis, the authors conclude that mercury is in a group of metals that are "... not very usual in geologic materials and probably have an anthropogenic origin", of which industry, garbage incineration and crematoria are listed as possible sources. No attempts to correlate mercury to any individual source was made in the article.

In contrast to the UK, Swiss and New Zealand research on mercury in soils surrounding crematoria, in May 2003, an article in the Norwegian newspaper *Aftenposten* ("Krematoriene forurenser for mye ") reported that while the Oslo crematoria were releasing mercury above recently established standards, the director of the crematoria stated that regular tests had been done of the soil in the area and that no dangerous values were found. The newspaper article did not provide any data on the actual levels of mercury in the soil. In response to a request from this reviewer, on May 27, 2003 Stein-Olav Hohle of the agency that is responsible for the crematoria wrote that their tests of the soil around the crematoria found no measurable increase in the amount of mercury in the soil surrounding the crematoria over background levels. At the time that the tests were done, the crematorium had performed some 70,000 cremations over a period of 30 years.

Also from Norway, data were obtained (Andersson) on topsoil analyses from the city of Trondheim, where 321 soil samples were taken. The data provided include the locations of the sampling with a precision of hundredths of a meter. Also provided were the location of three crematoria, along with their dates of operation and the number of cremations performed. In the data provided, no analysis was done of the relation of the mercury levels in the soil and the operation of the crematoria, but using the information provided, the following are the data from those locations within 400 meters of the crematoria, with the distances calculated by this reviewer.

Mercury Levels in Topsoil near Tilfredshet Crematorium, Trondheim, Norway
Distance in meters
Mercury in mg/kg
Crematorium operated 1925-1998, performed 26,000 cremations

Distance	38	40	43	44	50	60	62	73	94	108	111
Hg	0.110	0.294	0.527	0.213	0.055	0.089	0.138	0.197	0.038	0.162	0.015

Distance	112	121	155	170	171	187	217	266	315	392	396
Hg	0.110	0.342	0.145	0.203	0.071	0.114	0.259	0.015	0.367	0.195	0.216

Mercury Levels in Topsoil near Lademoen Crematorium, Trondheim, Norway
Distance in meters
Mercury in mg/kg
Crematorium operated 1962-1998, performed 12,000 cremations

Distance	53	78	192	230	249	251	286	321	339	381	396
Hg	0.143	0.136	0.547	0.340	0.015	0.222	0.084	0.094	0.041	0.424	0.262

Mercury Levels in Topsoil near Moholt Crematorium, Trondheim, Norway
Distance in meters
Mercury in mg/kg
Crematorium operated since 1998, performed 5,500 cremations

Distance	6	68	79	116	117	118	180	237	250	271	278	290	375
Hg	0.024	0.035	0.068	0.267	0.070	0.122	0.138	0.054	0.076	0.123	0.083	0.048	0.134

In reviewing the data of mercury deposition surround crematoria, it should be noted that some research concludes that atmospheric forms of metallic mercury have a very slow deposition rate (Capri) and that deposition is largely from the Hg^{++} ionic form. Thus, the mercury released from crematoria might not be expected to be deposited locally, but instead would contribute to deposition on a larger, perhaps global, scale.

National standards for mercury levels in soils have been set at greatly different levels. Tijhuis notes that for the topsoil analyses in Oslo, 4 exceeded the Norwegian norm value of 1.0 mg/kg, 23 exceeded the Dutch target value of 0.3 mg per kg, while none exceeded the Dutch intervention value of 10 mg/kg. In the UK (DEFRA, 2002), the most stringent guideline level is set for residential areas that have plant uptake, at 8 mg/kg, while the guideline for commercial/industrial areas is 480 mg/kg. Much lower levels are given in a US EPA OSWER publication in 2003, which references a 1998 report that found that critical limits for mercury in soil of 13 countries ranged from 0.1 to 2.1 mg/kg.

Mercury in Crematoria Ash

No published articles on mercury levels in crematoria ash have been found. However, in an email from Dr. Thomas Thomassen of Miltec in August 2002, he reported that he took 4 samples of ash from cremations and found that the mercury levels were less than 1 microgram/kilogram of ash. He noted that this low level was to be expected, given the high temperatures produced during cremation.

Mercury Deposits on Crematoria Chimneys

In an email from Dr. Thomas Thomassen of Miltec in Norway on September 12, 2002, he reported that he chipped off part of the brick material from a crematorium and found that the sample had 0.9 grams of mercury per kilogram of matter. He noted that it was easy to obtain a chipped sample, as the concrete was rotten due to exposure to acid mists from the cremations. In follow up tests, again near the top of the chimney, data were obtained on the surface dust, the cement between the bricks, and in samples that included pieces of the brick:

	mg Hg/kg sample
Surface dust on the bricks (black)	168
Cement between bricks (rotten)	20
Brick (solid chunk)	2.3

Dr. Thomassen believes that the level of mercury would be higher in lower levels of the chimney.

Regulation of Mercury Emissions from Crematoria

As of 2010, national mercury standards were found by this reviewer in only three European countries (Norway, Switzerland and the UK), although a 2003 report from Defra in the UK reports that national standards are also in effect in Austria, Belgium, Germany, The Netherlands, and Sweden. Also, Jensen reports that Denmark will have standards that go into effect at the end of 2010. In addition, standards were found at the state (Land) level in Germany, and a 2001 report by the French Senate (Miquel) listed specific standards at that time for a number of countries, as follows:

Cremation Emisisons Standards

Country	**(ng/Nm3)**
Belgium	0,2
Great Britain	0,2
Italy	0,1
The Netherlands	0,2
Sweden	- 90 % of inflow
Switzerland	0,2

However, citiations were not given for these standards and they may have subsequently changed, such as what has occured with the UK standard.

Norway's Pollution Control Authority (SFT) has developed air and water regulations for crematoria, which went into effect on January 1, 2003 for new crematoria and 2007 for existing crematoria. The regulations will result in a 95% reduction in mercury emissions from the largest crematoria (those with 200 or more cremations a year), according to an SFT news release issued on January 15, 2003. For air, the requirement is 0.05 mg/Nm^3, while for water, it is 2.0 µg/liter. The contacts at SFT are Signe Nåmdal at signe.namdal@sft.no and Bente Sleire at bente.sleire@sft.no.

A search of the Internet in March 2012 found that these standards were unchanged (Lovdata and Klima- og Forurensnings- Direktoratet).

In early July, 2001, two Norwegian environmental groups came out with a statement that it preferable to remove the teeth of the deceased before cremation rather than rely on control equipment. However, as in Maine, there is reluctance from the public to this approach. One Norwegian newspaper ran a poll on this through the Internet, and of 221 respondents, 40% said that they thought it was right to remove the teeth for environmental concerns, while 53% said it was not right to extract the teeth (7% had no opinion).

For Switzerland, according to an Internet article published in 2003 (Knellwolf), the standard is 0.2 mg of mercury emissions per hour of operation. The estimate is that each cremation contributes 3 grams of mercury. The article also notes that of the 59 crematoria ovens, only 13 are equipped with air pollution control equipment and that crematoria operators are screening out those corpses with large amounts of mercury fillings so that they are only cremated in the more modern ovens. An article by Schiller notes that the Swiss requirement went into effect at the end of 1991.

In the UK, standards were set in the fall of 2004 (Defra, 2004b) and then further revised in the spring of 2005 (Defra 2005). The original standard called for no regulation of existing crematoria and, for new crematoria, a maximum release of 150 milligrams per four cremations, with a concentration limit of 50 micrograms/cubic meter of exhaust gas. In the revised standard, 50% of all cremations at existing crematoria are to be subject to mercury abatement, with a deadline of 31 December 2012. The regulations allow for "burden sharing" – instead of each crematorium installing controlling equipment, several crematoria can share the cost of abatement equipment so that 50% of the cremations of the pooled crematoria have mercury abatement. Crematoria are to make their plans by the end of 2005.

In Germany, two states (Länder) (Sachsen and Brandenburg) had local standards, with Sachsen's at 0.2 mg/Nm^3, while Brandenburg's standard was 0.05 mg/ Nm^3. However, both of these standards were superseded by national regulations for crematoria as given in 27. BImSchV (the Federal Emission Regulation for crematoria, promulgated March, 1997), which contains no mercury standards. In addition, the German Association of Engineers published guidelines for crematoria (VDI 3891, promulgated August, 1992), but it also has no standard for mercury. However, in a February 2001 email from the German firm IFZW, it is expected that there will soon be an amendment of the 27th BImSchV with a limit for mercury of 0.05 mg/Nm^3. However, in a Internet search of the regulation on February 11, 2010, no standard for mercury was found in this regulation.

Denmark was checked for regulations, and an email message from the Danish equivalent of the EPA said that they do not have any mercury-related regulations, although they do have other crematoria regulations.

The requirements of The Netherlands was also reported in an report made to the International Cremation Association by Dutch National Association of Crematoria, although the actual standards were not provided.

For Sweden, an article in the March 18, 2002 edition of the Norwegian newspaper *Aftenposten* noted that there were no emissions standards for mercury from crematoria. Instead, the Swedish Naturvårdsverket has published guidelines, and that since 1995, some 20 crematoria have been built in Sweden with control equipment. The article quotes staff at the Swedish agency as saying that standards have not been developed due to the difficulties in measuring mercury emissions. According to one staff person, some measurements show that control equipment provides for clean emissions, but other measurements only result in a third of all mercury being trapped by the filters, and that either the measurements are in error or there is another path for the mercury.

However, those crematoria that do not have control equipment, may, in some cases, be required to install equipment. A newspaper article from 2008 notes that the crematorium in Luleå, Rena, is required to have the equipment in place by the end of 2010, or must close (Berglund). Similarly, the 2010 budget proposal for the Green Party of Stockholm is proposing to update the flue gas cleaning equipment, saying that Stockholm should be a leader on minimizing the environmental impact of the crematoria (Anonymous (2009)).

No national standards for mercury emissions from crematoria exist in the US. Under Section 129 of the Clean Air Act, the US EPA is required to set standards for a variety of air sources. Originally, the standards for crematoria were to be developed by November 2000, and in a *Federal Register* notice at that time, EPA set a new schedule to release its standards by November 15, 2005. However, in the *Federal Register* of December 9, 2004, EPA came to the conclusion:

> "... that the human body should not be labeled or considered 'solid waste.' Therefore, human crematories are not solid waste combustion units and are not a subcategory of OSWI for regulations. If EPA or States determine, in the future, that human crematories should be considered for regulation, they would be addressed under other authorities."

In California {Spicuzza), a group discussing the issue of mercury emissions from crematoria in 2000 recommended that teeth with amalgam fillings be extracted prior to cremation.

In Minnesota, the 2005 legislature had bills introduced (HF 0661 and SF 641) to require that dental mercury be removed before cremation. Neither bill was adopted.

However, a few years later, the State of Minnesota reached an agreement with the cremation industry to reduce their emissions by 75% by 2025 (Brooks). A 2008 report by the Minnesota Pollution Control Agency puts annual emissions of mercury from crematoria in the state at 80 pounds. A 2009 report by the same agencies contains the following timeline of activities:

- Study emission rates and develop better understanding of future trends by 2010.
- Study abatement alternatives and emissions-control options between 2008 and 2011. (Abatement options include alkaline hydrolosis, pulling or decoronating teeth.)
- Study social issues of abatement options.
- Implement recommended alternatives to achieve reduction targets.

In Maine, the 2005 legislature considered a bill (LD 1664, Cowger) to require crematoria to either remove amalgam fillings before cremation or to capture mercury emissions, but it was unanimously rejected by the Natural Resources Committee (Carrier). One newspaper reporter (Churchill) started off an article on the proposed legislation as "It's a ghoulish scenario: funeral home directors statewide prying teeth from the mouths of the dead.", and a later statement showed that it causes concerns even among crematoria operators, with the article noting 'Diane Fuller, manager of a crematorium in Auburn, called the notion "repulsive." '. Although the removal of teeth was supported as a method of control by both the Maine Natural Resources Council and the Maine Department of Environmental Protection, public support does not seem present. In a public opinion poll done by the *Portland Press Herald* on the Internet (Carrier), as of June 17, 2005, 72% of the 312 people who responded believed that crematoriums should not be required to remove teeth from cadavers.

In Minneapolis, Minnesota, an ordinance was adopted in the spring of 2006 with the following three components (Maccabee, 2006a and 2006b):

> **47.50. Registration of crematoria as an emissions** source adds crematoria to the types of businesses that must register with the Minneapolis Air Quality Management Authority.
>
> **47. 100. Disclosure of mercury emissions control at crematoria** requires crematoria to disclose the methods used to limit their mercury emissions.
>
> **47.115. Preventing increase in mercury emissions**, prevents the increase of mercury emissions into air or water from existing or future stationary sources.

A search on the ordinance in 2011 found some changes, however (City of Minneapolis, Minnesota Code of Ordinances). Registration is now required under 47.40 (b) (7). The 2011 fee for registering crematoria in Minneapolis is $53 per unit. (City of Minneapolis Regulatory Services). The requirement for a disclosure of control equipment was not found in the ordinance, but section 47.80 provides a limit on increases in mercury air emissions, with certain exemptions. These exemptions include an increase of less than 2 pounds a year and less than 20% of annual emissions, as well as for any facility which has signed an approved agreement with specified agencies for the elimination of mercury emissions, or Maximum Achievable Control Technology and a Continuous Emissions Monitoring system is installed and used under approval from the Minnesota Pollution Control Agency.

In Pennsylvania, two communities have adopted ordinances to control mercury from crematoria. West Reading's and Kulpmont's ordinances (Borough of West Reading, Borough of Kulpmont) set a limit of 0.05 mg/Nm^3 for all biowaste incinerators (including crematoria) which have the potential to release mercury. A continuous emissions monitoring system is required for data collection and the results can be averaged over a three hour period.

Control Technology for Mercury Emissions

As described in the previous section, one method of controlling mercury emissions from cremation is to remove the teeth with amalgam prior to cremation. Crematoria operators in the US already regularly remove other artificial devices prior to cremation, as shown by an Internet search. For example, the webpage of the Cayuga Crematorium, Inc. has a question and answer section which responds to the question:

> What happens to cardiac pacemakers, artificial implants, defibrillators, etc...?

with the answer :

> According to the Cayuga Crematorium, Inc. policy, pacemakers, defibrillators, battery operated devices, and artificial limbs are removed by the funeral home handling the case. Artificial implants such as hips and knees are cremated with the body and removed before the remains are pulverized.

The Missouri Cremation Services web page of frequently asked questions has a similar question and the answer shows that implants are at times removed:

> What is the policy in regards to disposing prosthetics, artificial hips, knees, etc.
>
> If requested, these items will be returned to the family. Provided there are not special request made by the survivors, these items are disposed of in accordance to state regulations.

And the Sierra Aftercare Center in California notes that pacemakers are required to be removed prior to cremation and lists a fee of $50 for this service.

In some cases, state laws also require the removal of certain products. For example, South Dakota requires the removal of pacemakers and hazardous implants, while Texas requires a declaration that the corpse does not ".. contain a pacemaker or any other material or implant that may potentially be hazardous or cause damage to the cremation chamber or the person performing the cremation." However, in Wyoming, while the statutes for crematories require the removal of pacemakers and other potentially hazardous implants (Section 11, (b)), the statutes also say "Removing or possessing dental gold or dental silver from deceased persons is prohibited " (Section 11, (a)).

A 2006 report by the Virginia State Advisory Bord on Air Pollution recommended that the teeth with mercury-containg restorations be extracted before cremation. Based on a cost of $25 per cadaver (8 fillings average), it was calculated that this would result in a cost of about $3,500 per pound of mercury caputured, based on an average of 3.2 grams per person.

Besides the removal of teeth prior to cremation, there are a variety of systems available for the control of mercury during crematoria. Selenium as a control media was mentioned in several articles reviewed from Sweden. During this preliminary search, four other types of control systems were found to be in use, one each from Germany, the Netherlands, Norway and Switzerland. More recently, Craft (2012) identified eighteen companies worldwide with pollution control equipment for crematoria.

In Sweden, as noted above, some 20 crematoria have been fitted since 1995 with air pollution control equipment for mercury. However, results are ambiguous due either to measurement problems or that there are other paths to which the mercury is going. A newspaper article in March 2002 notes the development of a liquid nitrogen freeze-dry process that is said to have no mercury emissions to the air. In the spring of 2004, the Swedish Chemicals Inspectorate reported on the general topic of mercury use in the country, including the issue of mercury releases from cremation. While the Reuters News Service and a Swedish publication (*NyTeknik)* reported that the report called for the extraction of teeth with amalgam fillings from the corpses prior to cremation, the agency – known as KEMI – said that this was not called for in their report.

One of the control processes is the addition of a selenium-containing ampoule to the firing chamber during cremations. Developed by Magnus von Platen of Emcoplate, AB, the ampoule is placed on the top of the casket, the selenium is said to chemically react with the mercury to form a compound that both is deposited on the inner wall of the crematoria oven or is trapped by the emission control system. The material that is deposited on the inner wall of the oven is said to also reduce the permeability of the oven wall, reducing the diffusion of mercury through the oven wall. One ampoule per cremation is required and in the fall of 2003, the cost per ampoule was SEK 170, or about $21.

Hogland reports on this system in a 1994 article and found that the selenium ampoules reduced the mercury levels in the exhaust from cremations from a maximum of 12.5 mg Hg/s to 2.3 and the mean from 2 grams per cremation to 0.3. Hogland also notes that in high concentrations, selenium and its compounds can be toxic to animals and people, but does not give what these toxic concentrations are, nor the amount of selenium and various selenium compounds that are released to the air and ash. The web page of Selenium Watch notes that increasing attention is being given to the toxic health and environmental effects of selenium, but a search for cremation did not produce any results.

The German organization known as IFZW says that its equipment can reduce mercury emissions from crematoria to a level of below 0.05 mg/Nm³. The German firm H. R. Heinicke has a web page that lists 16 crematoria which it has constructed and notes that its system also meets the German standard of 27. BImSchV.

In a report from the Dutch National Association of Crematoria to the International Cremation Federation (no date given, but 1999 or later), it was noted that the firm Vermeulen Product Engineering had developed a technology to meet the Dutch standards and removed 99.8% of the mercury found in the emissions. The system is said to be low cost. According to a US crematoria manufacturer (Rahill, 2005a), the cost of a control system in Europe would be about $300,000 installed, at an existing crematorium. He noted that in the US, the cost of a new crematorium would be about $80,000, while the cost of the air pollution control equipment for a new crematorium would be about $175,000.

In Norway, the Miltec firm (http://www.miltec-mercury.com) has control equipment for mercury and has installed this equipment on a crematorium. Trial runs in the spring of 2001 resulted in a 94% reduction in mercury emission to the environment.

In Switzerland, the firm of SEU Schenkel AG had developed an adsorption process for dioxins, furans and mercury. A system was installed on a crematorium in Basel in 1999 and a paper describing the firm's system was on the Internet, but the firm has been liquidated. The unit is said to be 99.9% effective in removing mercury, with the resultant effluent below 0.05 mg/Nm^3. In another article on the Internet (Schilling), it described the process used at the largest crematoria in Switzerland (and Europe), where each corpse is tested at the Nordheim crematorium, and those with fillings were sent to the oven with the mercury control equipment, which is said to remove 99% of the material.

An article by van Velzen, et. al., (2002) provides a review of generic control technologies for mercury emissions from solid waste incineration, and these may also be suitable for mercury emission control from crematoria.

Finally, OSPAR (2003b) calls for the use of Best Available Techniques (BAT) for controlling mercury emissions from crematoria by its contracting parties and briefly describes both four types of control technology: (1) co-flow filters, using an absorbent for mercury, with capture by a cloth filter, (2), a solid-bed filter, using absorbents such as cokes or zeolites, (3) traditional gas scrubbing techniques, and (4) honeycomb catalytic absorbers, using precious metal (gold/platinum) following particulate removal. Efficiencies are said to be up to 99.9%. Its previous document (OSPAR, 203a) includes more information, including a chart of known installations and also describes the use of selenium and ceramic reactors.

In the US, there are no known mercury control systems in use at crematoria. In a draft document by Craft for the California Air Pollution Control Officers Association, five potential systems are evaluated:

co-flow filter
gas scrubbers
honeycomb catalytic adsorber
sodium bicarbonate and activated carbon control system
solid-bed filter, using absorbents such as cokes or zeolites

These system include the four described in the OSPAR (2003b) document, adding the system of sodium bicarbonate along with activated carbon.

Alternative Technologies to Cremation

Three alternative technologies/methods are presently under use or development for the management of human corpses. Burial – whether traditional, "nature, or at sea – is the most well known, while deep freezing and alkaline hydroylsis are much newer.

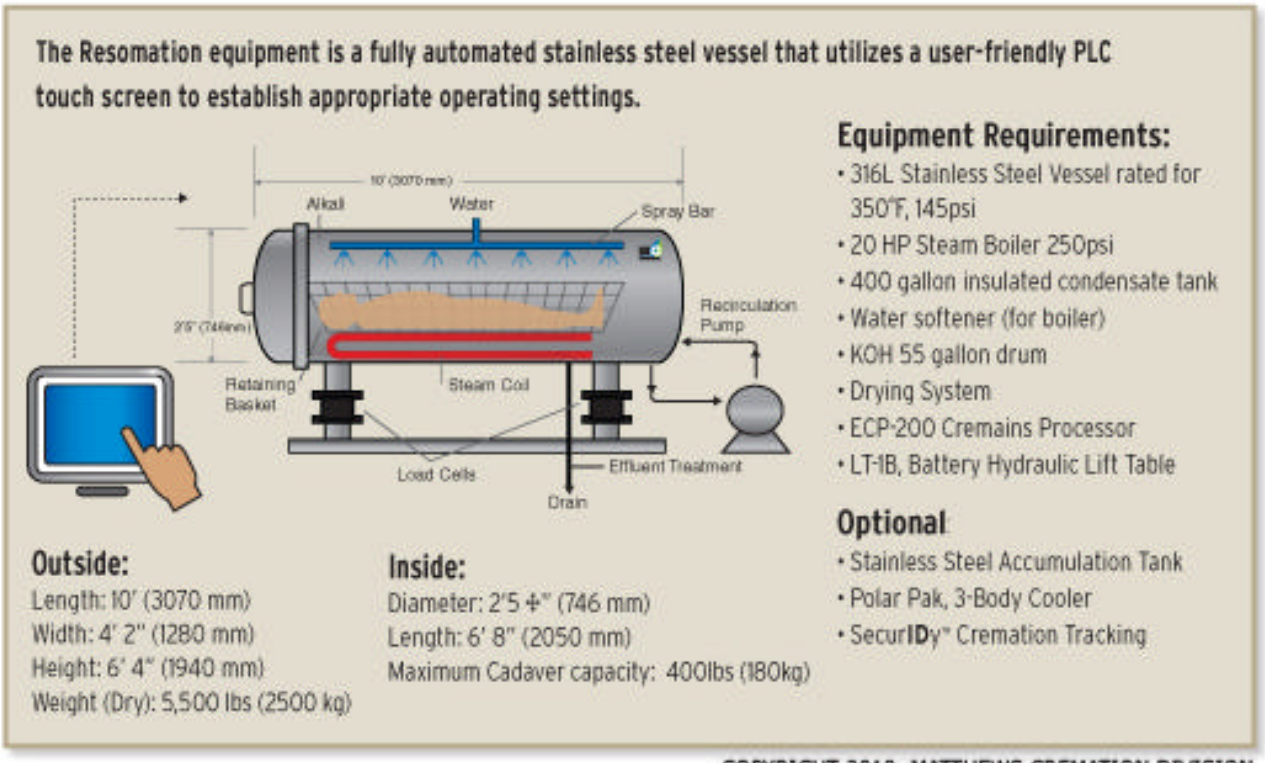
For a number of years, a freeze-dry technology using liquid nitrogen has been explored that would not involve any combustion and therefore could result in virtually no emissions of mercury to the air. Developed in Sweden by the t biologist Susanne Wiigh-Masak, in an article in a July 18, 2003 newspaper article (von Wachenfeldt), it noted that the inventor of this process had discussed this technique with clergymen, and found support for this method of handling the deceased. A web page has been established by the inventor's firm, Promessa, to describe and promote this process, which has been labeled "Promession". A web page of the cremation industry, Cremation Options, included an article about this approach in January 2010, with the title, "Cremation and A Cold Disposition". And a British firm, Cryomation, has announced on its web page that its technology is ready to be installed. The firm notes that one of the advantages of their process is the reduction of mercury emissions, stating that "30% of ALL global Mercury emissions can be attributed to cremation".

The web page FuneralSite.com was accessed in March 2012, where it says that the process is not available in the United States.

Alkaline hydrolysis is a much newer idea for the processing of human corpses, and has attracted a great deal of attention in the funeral industry – a Google search in March 2012 of the words "cremation"," alternative", "alkaline" and "hydrolysis" turned up 37,000 results, including a listing in Wikipedia.

Often known as "Resomation", it uses a mixture of water and potassium hydroxide, which heated to a high temperature at a high pressure to dissolve the soft tissues. In August, 2011, Bowdler reports that it was legal in seven states.

One of the suppliers of this equipment is Matthews Cremation Division, which also makes traditional cremation equipment. On its web page, it notes that this process has no mercury emissions and no air emisisons and needs no abatement. The firm's process is shown in the following diagram.



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Obviously it is not possible to review all of the world's literature related to mercury and cremations. One of the main sources of the literature has been from references found on the Internet, including searches in the following languages and with the terms listed below. The reviewer welcomes other references of relevant literature.

Danish	kviksølv krematorier	last done October 2003
English	mercury cremation	last done October 2003
German	quecksilber kremation	last done October, 2003
German	quecksilber krematorien	last done October 2003
Italian	cremazione mercurio	last done November 2004
Norwegian	kvikksølv krematorier	last done March 2012

Spanish	cremación mercurio	last done March 2012
Swedish	kvicksilver krematorier	last done February 2010
Swedish	kvicksilver krematoria	last done February 2010

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