Health Consultation

BETHEL UNIVERSITY

Emissions from a Mercury-containing Gymnasium Floor:
Mitigating exposures from mercury-containing polymer floors

ARDEN HILLS, RAMSEY COUNTY, MINNESOTA

EPA FACILITY ID: MND985685312

FEBRUARY 5, 2008

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

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Prepared By:

Minnesota Department of Health
Under A Cooperative Agreement with the
U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry

FOREWORD

This document summarizes public health concerns related to a gymnasium floor at a school in Minnesota. It is based on a formal site evaluation prepared by the Minnesota Department of Health (MDH). For a formal site evaluation, a number of steps are necessary:

1. *Evaluating exposure:* MDH scientists begin by reviewing available information about environmental conditions at the site. The first task is to find out how much contamination is present, where it is found on the site, and how people might be exposed to it. Usually, MDH does not collect its own environmental sampling data. Rather, MDH relies on information provided by the Minnesota Pollution Control Agency (MPCA), the US Environmental Protection Agency (EPA), and other government agencies, private businesses, and the general public.
2. *Evaluating health effects:* If there is evidence that people are being exposed—or could be exposed—to hazardous substances, MDH scientists will take steps to determine whether that exposure could be harmful to human health. MDH's report focuses on public health— that is, the health impact on the community as a whole. The report is based on existing scientific information.
3. *Developing recommendations:* In the evaluation report, MDH outlines its conclusions regarding any potential health threat posed by a site and offers recommendations for reducing or eliminating human exposure to pollutants. The role of MDH is primarily advisory. For that reason, the evaluation report will typically recommend actions to be taken by other agencies—including EPA and MPCA. If, however, an immediate health threat exists, MDH will issue a public health advisory to warn people of the danger and will work to resolve the problem.
4. *Soliciting community input*: The evaluation process is interactive. MDH starts by soliciting and evaluating information from various government agencies, the individuals or organizations responsible for the site, and community members living near the site. Any conclusions about the site are shared with the individuals, groups, and organizations that provided the information. Once an evaluation report has been prepared, MDH seeks feedback from the public. *If you have questions or comments about this report, we encourage you to contact us.*

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OR call us at:	(651) 201-4897 *or* 1-800-657-3908 (toll free call - press "4" on your touch tone phone)
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Table of Contents

Index of Tables

Index of Figures

Summary
The floor of a large gymnasium at a private university was found to emit mercury vapor at a rate that led to exceedance of the Minnesota Department of Health short-term and long-term exposure criteria for the protection of public health. The university requested that MDH summarize conclusions and recommendations from this investigation. This document is a technical summary of data from the investigation; and models developed to fit these data may be applied to other facilities with mercury-emitting polymer floors.

Emissions from the gymnasium floor have likely occurred since the flooring was installed in the early 1980's. Emission data from the spring of 2006 suggests that mercury vapor concentrations may have exceeded health criteria at various times since the floor was installed. Floor emissions appear to be temperature dependent with emissions likely to double for every increase of about 5 degrees Celsius in air temperature. Therefore, emission rates may have strong seasonal-dependence. The half-life of mercury in the flooring was calculated to be about 16 years. Ventilation was found to be effective at reducing air concentrations below levels of concern.

MDH developed a model for emissions and ventilation that could be verified at other locations with mercury-emitting floors. The model suggests that if the number of air exchanges per hour times the height of the gym is greater than or equal to 50 ft/hr, the mercury vapor concentration in the gym will likely remain below levels of concern. For example, a 25 foot high gym should have at least 2 air exchanges per hour.

Introduction
The Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Health (MDH) have been aware that some floors, often described as polyurethane, polymer, poured, rolled or mat surfaces, contain mercury. These floors are, generally, large gym floors that are predominantly in schools, and were laid or poured sometime between the 1960s and the mid 1990s. In 2006, MDH published a Health Consultation on 5 different mercury-containing gym floors (MDH 2006). That report showed gyms with mercury-containing polymer floors may have mercury vapor concentrations at levels of concern, especially for pregnant teachers.

In 2006, Bethel University (Bethel) had a large gymnasium, the Sports Recreation Center (SRC), with a mercury-containing polyurethane floor. Bethel invited the MPCA and MDH to conduct sampling of mercury vapor concentrations in the gym under different environmental conditions, prior to covering the floor in July 2006. This Health Consultation reports the results of testing that occurred during the period from May 2006 – June 2006 and provides a public health evaluation of potential exposures. In addition, this document contains analytical and emissions data from small chunks of flooring that Bethel provided. From the data, MDH has been able to develop floor emission and gymnasium ventilation models.

Site Background and History

Bethel University, with a student population of about 5200, is located in Arden Hills, Ramsey County, Minnesota. In May 2006 Bethel expressed interest in having emissions from a gym floor tested for mercury vapor, even though there already were plans to cover the floor with a new floor in the summer. On May 25, 2006 staff from MPCA and MDH visited the SRC on the campus of Bethel, with a Lumex Vapor Analyzer. The gym is about 150 feet (ft; east west) by 300 ft (north-south) by 30 ft (height). The entry way (northeast corner of the SRC), and a small section in the extreme NE corner of the gym, are tiled. Stairs in the entryway go up to a second floor where there are 2 offices. There is no second floor above the rectangular gym, but there is a storage/maintenance room along the west side of the gym that is accessible through double doors. Students use the gym throughout the year, and it is also rented out to community sports groups and sports camps.

The SRC gym floor was poured in place in the mid-1980's. It was poured in 2 different sections: a large blue, somewhat pebbled indoor track around the outside of 4 tan and smooth basketball courts running east-west. There was noticeable wearing (discoloration) of the floor under all baskets. The gym has no windows and has 4 sets of doors: in the NE corner, to the entryway; in the SW corner, to the outdoors; along the west wall, to the maintenance/storage room; and north of the maintenance/storage room doors, also along the west wall, is a rollup door to the outside. These doors are typically kept closed, except during the summer when they are opened for ventilation. Attachment 1 is a photograph of the inside of the gym, looking north. The entryway is on the right side of the picture.

Chemicals of Interest

Some synthetic polymer floorings contain heavy metals in measurable concentrations (Gandee 2003; Ohio Department of Health 2003; Michigan Department of Community Health 2004; Reiner 2005; MDH 2006; Oregon Department of Human Services 2006). Many of these floorings were manufactured using a 2-part system, with Parts A and B being mixed in a 10:1 ratio. MDH only has information about the Tartan Brand (Tartan) formulation which was discontinued before 1985. Tartan flooring Part A contained 0.1 - 0.2% phenyl mercuric acetate (PMA) and less than 0.1%, 0.6% and 0.1% lead octylate, lead chromate and lead oxide, respectively (Reiner 2005). PMA and lead octylate were used as catalysts to help harden the flooring, and lead chromate and lead oxide were used as pigments. Table 1 shows the total mercury, lead and chromium VI in Tartan floorings when they were first installed.

Table 1: Heavy metals in Tartan Flooring Formulation

Compound in 3M Flooring Formulation	MW	Metal in compound of interest			Compound in Part A of Formulation		Metal Concentration (ppm) in new floor at 10:1 (A:B)			
							Mercury		Lead	Chromium VI
		Mercury	Lead	Chromium VI	Min	Max	Min	Max	Max	Max
Phenyl mercuric acetate	337	59.6%			0.1%	0.2%	542	1083		
Lead octylate	493		42.0%			0.1%			382	
Lead chromate (VI)	323		64.1%	16.1%		0.6%			3497	877
Lead oxide	223		92.8%			0.1%			844	

(from Reiner 2005)

It is not known who manufactured the gym floor at Bethel University. It is likely that there are differences in formulations between manufacturers. While some companies used PMA in their floorings, other mercuric catalysts have been used in polyurethane products (e.g. phenylmercuric neodecanoate). In addition, different companies may have used different amounts of mercury, lead and chrome in their products.

There is a potential for 3 types of exposure to heavy metals from the gym floorings: inhalation of vapor or dust particulates from the flooring; dermal contact with the flooring, and; ingestion of residues or dust particulates from the flooring. Mercury is the only heavy metal with an appreciable vapor pressure. Therefore, it is the only chemical of interest that may be inhaled as a vapor. MDH is unaware of any data on the amount of heavy metals in dust in gyms: gyms with or without mercury-containing floors. In addition, MDH is unaware of any data on the composition of residues on mercury-containing floors, or the dermal or oral availability of those residues. Therefore, the analyses of exposures and hazards in this document are confined to those incurred by inhalation of mercury vapor.

Exposure to Mercury in Flooring

Mercury is used as a delayed-action catalyst in some floorings. Typically, it is in the form of an organic salt, such as phenyl mercuric acetate (PMA) or phenyl mercuric neodecanoate. Table 2, from The Handbook of Pesticide Toxicology (Krieger 2001), suggests that mercury in an enclosed space, as elemental mercury vapors or mercuric compound vapors, may reach concentrations above health criteria. In addition, the data suggests that if flooring contains mercury in almost any chemical form, the mercury is likely to volatilize, and mercury vapor may contaminate indoor air. Thus, even phenyl mercuric acetate may accumulate to levels above health criteria.

Table 2: Saturated Vapor Concentration of Mercury and Certain Groups of Its Compounds at 20°C

Group	Concentrations (mg/m^3)
Metallic mercury	14
Dialkyl compounds	10,000
Methyl compounds	0.3-94
Ethyl compounds	0.05-9.0
Phenyl compounds	0.001-0.017
Methoxyethyl compounds	0.002-2.6

(Krieger 2001)

The Lumex RA-915+ Mercury Vapor Analyzer (Lumex; OhioLumex Co., Inc., Twinsburg, Ohio) was used by the MPCA to measure mercury vapor concentrations in the SRC at Bethel University. It is a portable mercury vapor analyzer that has very little cross-sensitivity to chemicals other than elemental mercury (OhioLumex Co. Inc. 2007). Therefore, a Lumex will not detect volatile compounds that contain mercury, but only elemental mercury vapor. The lower detection limit for a Lumex is about 10 nanogram per cubic meter (ng/m^3). A Lumex measures sample concentrations every second, and can automatically report 10 and 30 second averages. A Lumex can be used to find mercury vapor hotspots, or it can be used to measure mercury vapor concentrations over a large area. These concentrations can then be compiled or averaged to form an understanding of exposures that may occur during a snapshot-in-time.

The chemical literature is not clear about whether the mercury vapor from PMA or other mercury compounds found in floorings is elemental mercury vapor, or if it is the vapor form of the mercuric compound in the flooring. Because the Lumex shows the presence of elemental mercury vapor only, it is clear that PMA (or other mercuric compound) is slowly being converted to elemental mercury. However, it is not known if PMA in the floor is converted to elemental mercury prior to volatilizing, or if it is converted to elemental mercury in air. This question needs additional research. If PMA is in vapor form in air, then the mercury concentrations in air that are reported in this document understate the actual total mercury concentrations in air.

Data

Mercury content of flooring material

A small sample of the flooring was cut out of the floor on May 31, 2006 and analyzed for density and mercury content. The sample had a density of 2.68 grams per cubic centimeter (g/cm^3) and contained 170 micrograms per gram (µg/g) or parts per million (ppm) mercury.

Mercury vapor

Mercury vapor concentrations were measured on 4 different occasions prior to covering the floor with a new surface. MPCA staff used a Lumex to measure mercury concentrations in different areas of the Sports Recreation Center, but sampling was mainly conducted in the gymnasium. Each recorded data point was an automatic average of thirty 1-second measurements. Means and standard deviations in Table 3 are based on data recorded in similar locations on the same date.

Table 3: Mercury Vapor Data

Sampling Date	5/25/2006	5/25/2006	5/25/2006	5/25/2006	6/9/2006	6/9/2006	6/9/2006	6/16/2006	6/30/2006	6/30/2006	6/30/2006	6/30/2006
Sample Location	Gymnasium	Offices	Foyer	Maintenance Shop	Gymnasium			Gymnasium	Gymnasium			Foyer
Ventilation	Fans Off, Doors & Windows Closed	Doors Closed	Outside Doors Closed	Outside Doors Closed	Fans Off, Doors & Windows Closed			Fans On, Doors & Windows Open	Fans On, Doors & Windows Closed			Outside Doors Closed
Gym Temperature (C)	21.7				24.2			25.1	24.0			
Approximate height from floor (ft)	3	3	3	3	5	15	25	3	3 - 5	15	25	3
Mean [Hg] (ng/m^3)					2332 (All readings)				554 (All readings)			
	2699	979	2000	1636	2534	2326	2115	434	553	559	550	323
Standard Deviation (ng/m^3)	374	102		88	232	363	106	90	128	92	41	
Number of 30 sec readings	5	3	1	2	19	22	17	11	8	3	3	1

Data were also collected on December 1, 2006 after a new floor was poured over the mercury-containing floor. These data are shown in Table 4.

Table 4: December 1, 2006 Mercury Vapor Data; new flooring in place

	Mercury (ng/m^3)	Temperature (C) Air	Temperature (C) Floor	Relative Humidity	n=
Mean	71.3	18.7	17.7	14%	61
StDev	17.7	1.2	1.0	0.7	

Discussion

Mercury Vapor Toxicity

General mercury vapor toxicity

Dermal (skin) exposure to mercury and ingestion (swallowing) of mercury are unlikely to be significant sources of exposure, because dermal and gastrointestinal absorption of elemental mercury is limited (ATSDR 1999). Therefore, breathing mercury vapor emitted from gymnasium floorings is of greatest concern to MDH.

MDH recommends safe chemical exposure criteria for the general public and individuals with no expectation of workplace exposure. MDH uses health-based reference values from different organizations, including the US Environmental Protection Agency (EPA) and California Office of Environmental Health Hazard Assessment (OEHHA), based on availability.

Chronic Air Exposure Reference Values for Elemental Mercury

EPA's integrated risk information system (IRIS) database specifies a Reference Concentration (RfC) for chronic exposure to mercury vapor of 300 ng/m^3 (EPA IRIS 2004). An RfC is an exposure concentration that is not expected to result in adverse health effects to most people, including sensitive subpopulations, exposed over a lifetime. The mercury RfC is derived from multiple studies of occupational exposures. Most studies were conducted with dentists or employees in chlor-alkali or fluorescent light bulb plants who were exposed to mercury vapor. The observed critical effects included hand tremors, memory disturbances, and slight subjective and objective evidence of autonomic nervous system dysfunction. The lowest observable adverse effects concentration (LOAEC) in the occupational studies used by EPA to develop the RfC was 25,000 ng/m^3. Affected workers had mean whole blood mercury concentrations of 10–12 micrograms per liter (µg/L). Adjusted to a 24 hour, 7 days per week exposure, the adjusted lowest observable adverse effect concentration ($LOAEC_{adj}$) = 9,000 ng/m^3. An uncertainty factor of 10 is applied to compensate for the use of a LOAEC (as opposed to a concentration at which no effects are seen) and for variations in human sensitivity, and an uncertainty factor of 3 for lack of studies on the reproductive and developmental effects of elemental mercury. The resulting RfC (300 ng/m^3) is assumed to be a safe average exposure level for a lifetime.

The calculation of an RfC assumes that there is a threshold level for effects. A threshold for toxicity from mercury vapor exposure is presumed in the standard model used by EPA for noncarcinogens.

The California Office of Environmental Health Hazard Assessment (CA OEHHA) derived a Reference Exposure Level (REL) for chronic inhalation exposure to mercury from the same studies used to develop the IRIS RfC. However, instead of using the cumulative uncertainty factor of 30 used by EPA, CA OEHHA has adopted an uncertainty factor of 100. This is based on a factor of 10 for the uncertainty of using an LOAEC exposure instead of a "no observable adverse effects concentration" (NOAEC) when calculating the REL. It also includes a factor of 10 for human intraspecies variability. The California REL for mercury (elemental and inorganic) is 90 ng/m^3 (CA OEHHA 1999a).

The Agency for Toxic Substances and Disease Registry (ATSDR) has a health-based chronic minimum risk level (MRL) for mercury of 200 ng/m^3 (ATSDR 1999). This MRL is calculated from the same data used to calculate the IRIS RfC. However, the MRL calculation assumes that in an occupational exposure, one third of the daily inhaled air each working day is contaminated. The EPA RfC assumes that half of the working daily inhalation is contaminated.

MDH uses IRIS RfCs for giving exposure advice when there is not an HRV. MDH has some concern that the EPA RfC uncertainty factor of 30 may not sufficiently protect sensitive subpopulations given that the basis of the underlying value is an LOAEC. The California chronic mercury REL does provide this additional protection. However, practical application of the mercury REL at contaminated sites may be problematic because personal exposure to mercury from other sources, including dental amalgams, may be in the range of the REL. MDH therefore recommends that the EPA criterion be used, but that care be taken to ensure that chronic exposures to mercury from all sources do not exceed this level.

Acute Air Exposure Reference Value for Elemental Mercury and Inorganic Salts
California OEHHA developed an acute REL for mercury vapor based on developmental effects in the offspring of exposed rats. Central nervous system effects in pups were noted following exposure of dams to 1.8 mg/m^3 for 1 hour/day during gestation. A cumulative uncertainty factor of 1,000 is attached to this REL because it is based on a LOAEC (10x), the primary study was an animal study (10x), and human response to all chemicals is variable (10x) (CA OEHHA 1999b).

MDH recommended exposure limits for mercury vapor from flooring
Based on the EPA RfC (EPA IRIS 2004) MDH developed a mercury vapor exposure criterion for teachers and students in the 2006 Health Consultation on mercury containing floors (MDH 2006). Table 5, adapted from the 2006 Health Consultation, shows that concentrations at or below 740 ng/m^3 will not be hazardous if a teacher's exposure is limited to 40 hours a week or a student's time exercising in the gym is less than 16 hours per week, both averaged over a year. This assumes that outdoor and indoor mercury levels are 4 and 55 ng/m^3, respectively.

Table 5: Modeled Weekly Mercury Exposures

	Exposure Duration (hr/wk)				Air Concentration (ng/m^3)			Breathing Rate (m^3/hr)				Hg Inhalation @ RfC (ng/wk)
	Gym	Outdoor	Indoor		Gym	Outdoor	Indoor	Gym	Outdoor	Indoor		
			Awake	Sleeping						Awake	Sleeping	
RfC exposure	40	14	58	56	300	300	300	0.8	1	0.4	0.3	25,800
Teacher Exposure	40	14	58	56	**736 ***	4	55	0.8	1	0.4	0.3	25,800
Student Exposure	**16 ****	14	82	56	740	4	55	1.9	1	0.4	0.3	25,800

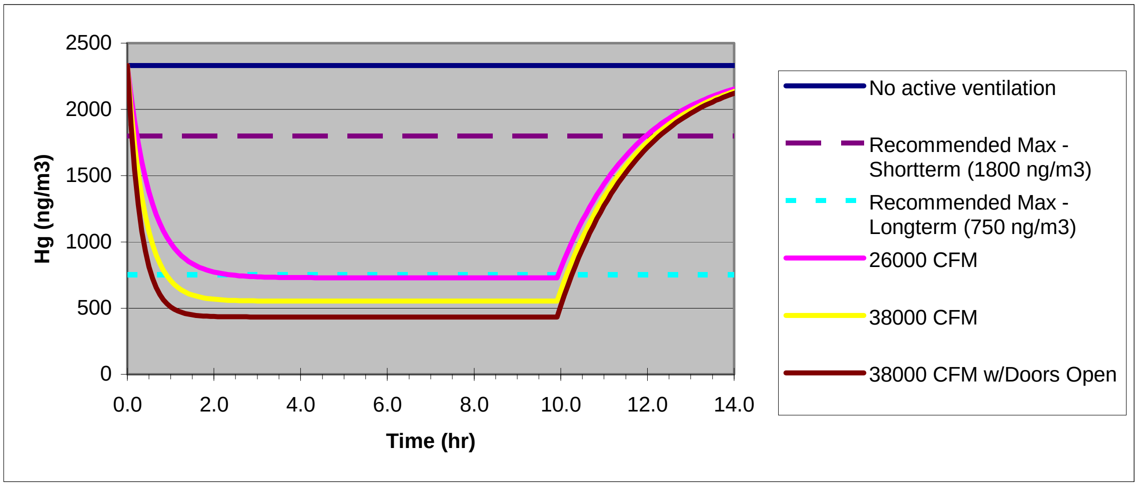
Bold values are calculated from expected exposures and presumed air concentrations, and with a total weekly inhalation limit of 25,800 calculated from exposure at the RfC.
* Suggested exposure limits for teacher and student at 40 and 10 hours exposure per week, respectively
** Suggested exposure duration limit for student with 740 ng/m^3 gymnasium mercury vapor concentration

For a chronic exposure criterion, such as the elemental mercury RfC, comparison with a yearly average exposure is appropriate. Therefore, exposure limits may be adjusted upward if exposures do not occur regularly over a year. However, because it has not been demonstrated that there is a threshold below which there is no effect of mercury exposure, MDH typically recommends minimizing mercury vapor exposures.

Using Ventilation to Control Mercury Vapor Concentrations

Mercury vapor concentrations in Table 3 show that the mercury vapor in the gym is well mixed, even when the ventilation is off. In addition, the data shows that active ventilation of the SRC decreases the mercury vapor concentration below health criteria. The attached Appendix contains a mercury emission model for the SRC floor, quantifying the mercury vapor concentration-dependence on ventilation. Figure 1, below, shows how ventilation can, within a couple of hours, bring the mercury vapor concentration below 750 ng/m^3.

Figure 1: Modeled Mercury Vapor Concentrations in SRC Gym With Different Ventilation Rates (cu.ft./min; CFM) @ 24° C



The attached Appendix contains the derivation of a model that can be used to calculate the amount of ventilation that may be needed to keep mercury vapor concentrations below the recommended concentrations in a gym that is similar to the SRC and has a similar floor. If the air in the gym is exchanged with fresh air at an hourly rate (turnovers per hour) that is greater than or equal to 50 divided by the gym height (in feet), mercury vapors in a gym similar to the SRC are likely to remain below levels of concern. (i.e. TO (1/hr) = 50 ft/hr / height (ft))

The Appendix contains a fuller discussion of the uncertainties of the ventilation model, but an important uncertainty is the temperature dependence of floor emissions. The vapor partial pressure of PMA doubles for every 4.8° C increase in temperature (Phillips et al. 1959). Therefore, as the temperature of the floor decreases in the winter, the emissions will also decrease significantly. While it is likely that this decrease is related to the temperature-dependent change in partial pressure of the mercury catalyst, there may be other factors that also contribute to the temperature dependence of emissions from flooring (e.g. flooring permeability).

Covering a mercury-containing floor with a new floor

The new SRC flooring is a poured mercury-free rubber floor, with no seams except where the track meets the inner basketball courts. It has been caulked around the perimeter, with a baseboard glued on the wall. Some spots appeared to be missing caulk. The airflow and turnover with outdoor air was constant during sampling on December 1, 2006 (15% damper opening). Bethel is planning to run ventilation at a constant rate, 15% damper, during winter, spring and fall, and summer ventilation is planned to be 100%. Ventilation is planned from 6 am to 10 pm, and at all times when the facility is occupied. Bethel has said that ventilation may change in the future when the off-gassing of organic compounds from floor is complete.

If a new floor is placed on top of a mercury-containing floor, it is possible that mercury vapor will penetrate through the new flooring, or that mercury vapor will leak out along the seams and edges of the new flooring. Prior to the SRC, MDH had not seen any data on this type of flooring replacement. Table 4 (Section Data, Mercury Vapor, above) shows the results of sampling in December 2006. These data show little mercury vapor leakage from the underlying mercury-containing floor.

Over time the effectiveness of a new floor as a barrier to mercury vapors may change. In addition, other types of new flooring may be less effective in encapsulating the mercury-containing floor. Overlain wooden floors, that either have seams or cracks, may be particularly problematic because of the potential for expansion/contraction cracks to increase over the years as the floor heats, cools and undergoes changes in material moisture. MDH is unaware of any testing of the effectiveness of different sealants to contain mercury vapor, but it is likely that sealants will slow but not stop emissions from flooring.

If a mercury-containing floor is covered with a new floor, a record will be necessary to ensure that when the new floor is replaced in a couple of decades, construction and disposal occur with appropriate safeguards to control the mercury in the floors and limit exposures to mercury.

Bethel University was aware of MDH concerns about covering an old floor with a new floor. However, there were other factors they considered when they made their decision to cover the flooring. First, the new flooring needed a strong firm base, which would have required a reconstructed subflooring, if the old flooring was removed. This would have made the project considerably more complicated and costly. In addition, disposal options for mercury-containing floors in Minnesota are very limited and expensive, and may result in the resale of the mercury in the flooring for use in other processes or products.

Evaluation of exposures and health concerns

Since the 1960s mercury-containing floors have been used throughout the United States and other countries. While it is likely exposures to mercury vapors sometimes exceeded health-based criteria, potential effects, if they occurred, were probably subtle and may have not have been clinically apparent.

Data from the SRC suggest that those who used the gym since it was installed in the early 1980s may have been exposed to concentrations of mercury vapor above health-based criteria. Due to the decreasing concentration in the flooring over time, exposures when the flooring was first installed may have been about 3 times higher than they were when the floor was covered in 2006 (see Appendix). In addition, emissions were likely higher during the summer when the temperature of the flooring is the highest, and when ventilation is set at a minimum. According to the maintenance engineer, ventilation in the SRC was usually off unless heat was needed. Therefore, while doors to the outside were often open when the temperature was pleasant or hot, the active ventilation system was usually off.

Of greatest concern are exposures to fetuses of women who exercised in the gym during pregnancy. Animal studies have shown subtle developmental or behavioral deficits in fetuses exposed over a short period, albeit to much higher concentrations than those found in the SRC. Because of uncertainties in extrapolating from effects on animals to effects on humans, MDH and other public health agencies incorporate uncertainty factors into exposure criterion used to evaluate exposures. Therefore, while the concentrations in the SRC were well below the concentrations at which effects were seen in animals, exposures still occurred over the short-term health protective criterion (1800 ng/m^3). In addition, long-term (yearly) average exposures above 740 ng/m^3 over an average of 16 hours per week while exercising, or 40 hours per week for someone (such as a coach) who is not exercising, were also possible.

Conclusion

Exposure to mercury vapor at concentrations found in the SRC has not been associated with adverse health effects in humans or laboratory animals. However, mercury vapor concentrations measured in the SRC when ventilation was off were above MDH short and long-term exposure criteria for protection of public health. In June 2006, when the mercury vapor problem was identified, ventilation in the gym was increased to keep mercury vapor concentrations below health criteria. Furthermore, later in the summer of 2006 the flooring was covered with a new mercury-free synthetic floor. Since June 2006, when ventilation was used to control mercury vapor concentrations and the subsequent covering of the flooring, conditions in the SRC suggest No Apparent Public Health Hazard as defined by the Agency For Toxic Substances and Disease Registry (http://www.atsdr.cdc.gov/COM/hazcat.html).

Recommendations

There are 2 types of MDH recommendations: first are recommendations for the Bethel University SRC flooring; and second are general recommendations from MDH on mercury-containing floors that are a result of MDH work related to the Bethel University flooring.

Bethel University-specific recommendations:

1. Active ventilation should be used or mercury concentrations in air should be measured every few years.
2. Records should be maintained in a place where they will come to the attention of appropriate University authorities whenever there is a potential that someone could be exposed to the mercury-containing floor. This would include major construction where the floor, or parts of the floor are exposed; occurrence of a fire that exposes or burns part of the floor; and when the gym floor needs replacing or repairing. If the flooring or any parts of the flooring are removed, the flooring should be disposed of according to MPCA regulations and guidance.

General recommendations on mercury-containing floors:

1. Gymnasiums with mercury containing floorings should be actively ventilated.

- While the current model has uncertainties and suggests large variability in emissions related to the temperature of the flooring, the model demonstrates that if ventilation (turnovers per hour) is greater than or equal to 50 ft/hr divided by the gym height (ft), ventilation may be sufficient to maintain a gym concentration below the MDH criterion of 740 ng/m^3.

2. Mercury-containing floors do not need to be replaced if mercury vapor concentrations are always below health criteria. However, seasonal changes in mercury emission rates should be expected and records should be maintained such that: administrations and staffing understand the importance of continuing ventilation; and the composition of the flooring will be known when the flooring is replaced in the future.
3. If a school is planning to cover mercury-containing floors school officials should:
    - consult the MPCA on the regulations that may govern this action;
    - continue to ventilate the gym or test for mercury every few years;
    - maintain records such that the flooring is clearly identified as mercury-containing and activities that may affect emissions or exposures will be identified.
4. MPCA should develop a consistent policy for disposal of mercury-containing floors that assures the mercury is not reused; longterm emissions to the environment are minimized; and that cost is not a deterrent to proper removal and disposal.
5. If it is uncertain whether a synthetic (rubber-like, polyurethane) flooring contains mercury, then responsible school officials should:
    - Actively ventilate the room at least 2 hours prior to use and continue ventilating throughout the time that the room is in use.
    - Determine whether the flooring contains mercury by having a sample of flooring analyzed or by measuring mercury vapor concentrations in the room with windows and doors closed and the ventilation turned off.
6. Schools should test mercury vapor concentrations in air when the temperature is hot and ventilation is at the lowest level used when the gym is occupied during the year.

Public Health Action Plan

MDH will continue working with Bethel University to ensure that elevated exposures to mercury do not occur. MDH will continue to acquire data on floors that contain mercury in order to validate and refine our recommendations. MDH will work with the MPCA and the Minnesota Department of Education to publish an information sheet addressing mercury-containing floorings.

This consultation was prepared by:

Carl Herbrandson, Ph. D.
Toxicologist
Site Assessment and Consultation Unit
Environmental Surveillance and Assessment Section
Minnesota Department of Health

References

Agency for Toxic Substances and Disease Registry (1999). Toxicological profile for mercury. Research Triangle Institute under contract no. 205-93-0606. March 1999. http://www.atsdr.cdc.gov/toxprofiles/tp46.html

California Office of Environmental Health Hazard Assessment, (1999a). Mercury Chronic Reference Exposure Level. OEHHA, Last updated 1999, http://www.oehha.ca.gov/air/chronic_rels/pdf/7439976.pdf

California Office of Environmental Health Hazard Assessment, (1999b). Mercury Acute Reference Exposure Levels. OEHHA, Last updated March 1999, http://www.oehha.org/air/acute_rels/pdf/HgA.pdf

Office of Health and Environmental Assessment, Environmental Criteria Office (2004). Integrated Risk Information System. EPA IRIS. Environmental Protection Agency, U.S. http://www.epa.gov/iris/

Gandee, D.B. (2003). Mercury Contamination of Polyurethane Flooring. BECO, April 10, 2003, Gandee & Associates, Inc., Lawhon & Associates, Inc., URS Corporation.

Krieger, R.I. (2001). Handbook of Pesticide Toxicology, Academic Press. Page 1372.

Minnesota Department of Health (2006). Mercury-Containing Polyurethane Floors in Minnesota Schools: Mercury Vapor Release/Athletic Polymer Floors. St. Paul, MN. Health Consultation, Concurrence from the Agency for Toxic Substances and Disease Registry. September 28, 2006. http://www.health.state.mn.us/divs/eh/hazardous/topics/mercuryvapor.pdf

Michigan Department of Community Health (2004). Mid-Michigan Mercury Floor. Middleton, Gratiot County, Michigan. Health Consultation, Concurrence from the Agency for Toxic Substances and Disease Registry. May 6, 2004. http://www.michigan.gov/documents/Middleton_(mercury_in_flooring)_102577_7.pdf

Ohio Department of Health (2003). Mercury Exposures from 3M Tartan Brand Floors. Westerville, Franklin County, Ohio. Health Consultation, Concurrence from the Agency for Toxic Substances and Disease Registry. March 19, 2003. http://www.atsdr.cdc.gov/HAC/PHA/westerville/wes_toc.html

OhioLumex Co. Inc. (2007). Telephone conversation Carl Herbrandson, Minnesota Department of Health. Cross-sensitivity of the Lumex RA-915+ Mercury Vapor Analyzer. Twinsburg, OH. August 3, 2007.

Oregon Department of Human Services (2006). Salem-Keizer School District 3M Flooring: Public Comment Release. Superfund Health Investigation and Education Program (SHINE), Salem, Oregon. Health Consultation Draft, submitted to the Agency for Toxic Substances and Disease Registry. March 2006.

Phillips, G.F., B.E. Dixon and R.G. Lidzey (1959). The volatility of organo-mercury compounds. J. Sci. Food Agric 10: 604-610.

Reiner, E.A. (2005). Letter to C. Herbrandson, Minnesota Department of Health. Re: Questions About Rubber-Like Floors. 3M Environmental Health and Safety Operations, St. Paul, MN. September 23, 2005.

ATSDR CERTIFICATION

This Bethel University Health Consultation was prepared by the Minnesota Department of Health under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the health consultation was begun. Editorial review was completed by the Cooperative Agreement partner.

Trent LeCoultre
Technical Project Officer, CAT, CAPEB, DHAC, ATSDR

The Division of Health Assessment and Consultation, ATSDR, has reviewed this public health consultation and concurs with the findings.

Alan Yarbrough
Team Lead, Cooperative Agreement Team, CAPEB, DHAC, ATSDR

Attachment 1

Appendix

Modeling and Mitigating exposures from mercury-containing polymer floors

Appendix

Table of Contents

Index of Figures

Controlling Mercury Vapor Concentration in the Bethel Gymnasium

It is reasonable to expect that the mercury emissions from a floor remain the same from day to day, if the temperature is constant. Therefore, when ventilation changes, mercury vapor concentrations will be different, with more ventilation resulting in lower mercury vapor concentrations. This is shown in the data summarized in the Health Consultation, Table 3. The overall average mercury vapor concentration with no ventilation was 2332 ng/m^3; with ventilation turned on the mercury vapor concentration was 554 ng/m^3; and with the ventilation on and the outside doors open the mercury vapor concentration was 434 ng/m^3. All rooms will have some ventilation or removal of mercury vapor, whether through leaks or by sorption or penetration into or through the walls and ceiling. However, the data with no additional ventilation and the data with a known amount of ventilation can be used to calculate the mercury vapor emission rate from the flooring.

Hg_{in} (ng/min) = Hg_{out} (ng/min) *Equation 1.*

If the mercury vapor concentration in the gym is constant, and where:
Hg_{in} is the total amount of mercury emitted by the flooring and
Hg_{out} is the total amount of mercury lost from gym air.

Hg_{out} is mercury lost through the active ventilation system and the small amount of ambient, passive, unmeasured ventilation and vapor penetration through cracks and into the walls of the gym. The SRC has 2 ventilation fans, each rated at 19,000 cubic feet per minute (ft^3/min - often referred to as CFM), shown as Vent. (Note: 35.3 $ft^3 = 1\ m^3$.) The unknown passive loss rate (in ft^3/min) can be represented by an unknown, constant loss, referred to as k_{loss}. Replacing for Hg_{out}

$Hg_{in} = [Hg]*k_{loss} + [Hg]*Vent$ *Equation 2.*

and

$k_{loss} = (Hg_{in} / [Hg]) - Vent$ *Equation 3.*

Where [Hg] is the measured mercury concentration in gym air.

The loss rate, as well as the floor emission rate, are assumed to be similar under different ventilation conditions. Therefore, if data are available from 2 different, known ventilation conditions, the following expression applies:

$(Hg_{in} / [Hg]_1) - Vent_1 = (Hg_{in} / [Hg]_2) - Vent_2$ *Equation 4.*

Which can be solved for Hg_{in} :

$Hg_{in} = (Vent_1 - Vent_2) / (1/[Hg]_1 - 1/[Hg]_2)$ *Equation 5.*

Substituting data from Table 3 (Health Consultation). (note the gym floor temperatures were similar, 24 and 24.2°C, during these sampling events.)

$Hg_{in} = (0\ ft^3/min - 38{,}000\ ft^3/min) / (1/2332\ ng/m^3 - 1/554\ ng/m^3)$

$Hg_{in} =$ 781,871 ng/min

The area of the gym floor is 45,000 ft^2. Therefore, the mercury emissions per unit area from the floor at about 24°C is:

$Hg_{in\ (per\ unit\ area)} = 17.4\ ng/ft^2/min$

And from Equation 3,

k_{loss} = 781,871 ng/min / 2332 ng/m^3 * 35.3 ft^3/m^3 – 0 ft^3/min
k_{loss} = 11,800 ft^3/min

The ventilation required to maintain mercury vapor concentration below levels of concern in the SRC can be calculated from the following equation, which is a rearranged Equation 3:

$Vent_{target}$ = (Hg_{in} / $[Hg]_{target}$) - k_{loss} *Equation 6.*

The target mercury concentration is 740 ng/m^3 (from Health Consultation, Table 5). Therefore:

$Vent_{target}$ = 781,871 ng/min / 740 ng/m^3 * 35.3 ft^3/m^3 – 11,800 ft^3/min
$Vent_{target}$ = 25,500 ft^3/min

The volume of the SRC (Vol) is 1.35 million cubic feet. The number of air turnovers per hour (hr^{-1}) (TO) in the gym can be calculated from:

TO = Vent / Vol *Equation 7.*
TO = ft^3/min * (min/hr) / ft^3

k_{loss} can be converted from ft^3/min to passive turnover per hour or TO_{loss} using Equation 7:

TO_{loss} = k_{loss} / Vol
TO_{loss} = 11,800 ft^3/min * 60 min/hr / 1,350,000 ft^3
TO_{loss} = 0.52 hr^{-1}

Similarly, $Vent_{target}$ can be converted to TO_{target}:

TO_{target} = 25,500 ft^3/min * 60 min/hr / 1,350,000 ft^3
TO_{target} = 1.13 hr^{-1}

These calculations suggest that at a temperature of 24° C (75° F), total SRC ventilation should be about 37,300 ft^3/min or greater (25,500 ft^3/min through active air handlers and 11,800 ft^3/min-equivalent additional loss) to maintain a mercury vapor concentration at or below 740 ng/m^3. This is an active ventilation rate of 1.13 TO/hr and assumes an additional loss rate of 0.52 TO/hr, for a total ventilation of about 1.65 TO/hr.

Applying Bethel SRC Models To Other Gyms

The loss factor (k_{loss}), which represents mercury vapor loss not attributable to known ventilation, is different for every gym. Therefore, for a ventilation model to be protective, if the loss is not known, the non-active ventilation loss in a gym should be assumed to be 0 ft^3/min or 0 TO/hr.

Mercury emissions are a function of the surface area of the floor, whereas, ventilation is a function of the room volume. Therefore, if mercury vapor emissions, per unit area, are consistent between gyms with similar composition floorings, the differences in mercury vapor concentrations between gyms (at similar temperatures) will be a function of the volume and the surface area of the gym.

From Equation 1 and 2:

$Hg_{in} = Hg_{out}$

$Hg_{in} = [Hg]*Vent$

$Hg_{in\ (per\ unit\ area)} * SA = [Hg]_{target}*Vent_{ttl}$ *Equation 8.*

Where SA is the surface area of the mercury-containing flooring (assumed to be equal to the total surface area of the gym floor) and $Vent_{ttl}$ is the total ventilation including active and passive ventilation.

Rearranging Equation 8:

$Hg_{in\ (per\ unit\ area)} / [Hg]_{target} = Vent_{ttl} / SA$

Because it is assumed that the emissions per unit area from floors are similar and a target mercury vapor concentration is known, a required ventilation rate can be calculated from a gym's surface area. Or with further modification of Equation 8:

$Hg_{in\ (per\ unit\ area)} / [Hg]_{target} = Vent_{ttl} / (Vol / ht)$

Where ht is the gym height and SA = Vol / ht.

Substituting TO from Equation 7, above:

$Hg_{in\ (per\ unit\ area)} / [Hg]_{target} = TO * ht$ *Equation 9.*

From the SRC data:

$Hg_{in\ (per\ unit\ area)} = 17.4\ ng/ft^2/min$

$[Hg]_{target} = 740\ ng/m^3 = 20.95\ ng/ft^3$

Applying these data to Equation 9:

$TO * ht = 17.4\ ng/ft^2/min * 60\ min/hr / 20.95\ ng/ft^3 = 49.8\ ft/hr \sim 50\ ft/hr$

This suggests that mercury vapor concentrations in a gym (with emissions similar to the SRC at 24° C) will remain below the MDH level of concern of 740 ng/m^3 if the TO (hr^{-1}) times gym height (ft) is greater than or equal to 50 ft/hr. In the SRC, this requires a TO of:

$TO \geq 50\ ft/hr / 30\ ft$

$TO \geq 1.67/hr$

For comparison, from the Bethel Gymnasium section, above:

$TO_{loss} = 0.52\ hr^{-1}$

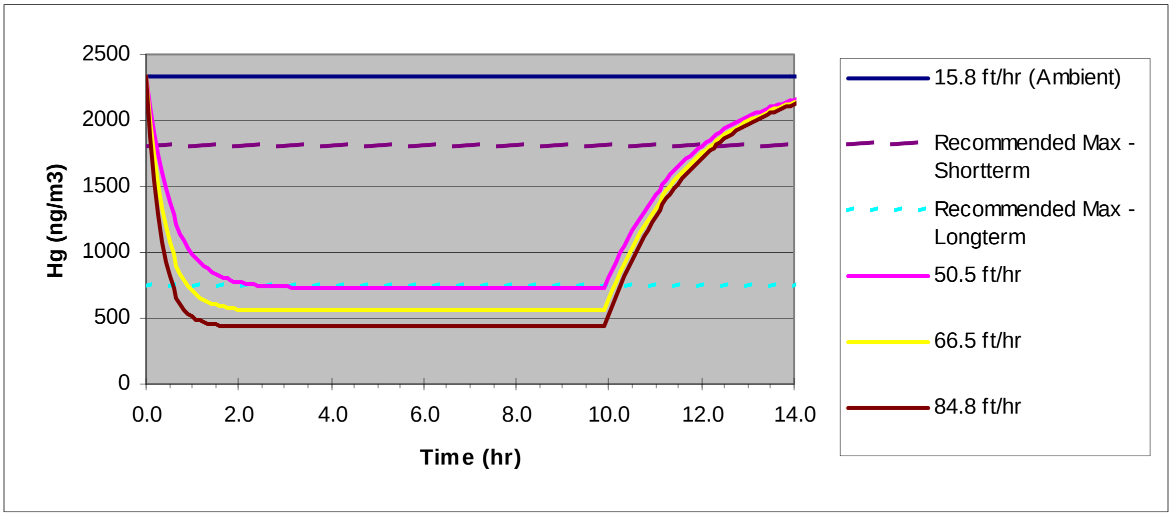
$TO_{target} = 1.13\ hr^{-1}$

$TO = TO_{loss} + TO_{target}$

$TO = 1.65\ hr^{-1}$

If the active ventilation is off over night, but is turned on at the beginning of the day, it will take some time for the mercury vapor concentration to drop below levels of concern. Figure 1 shows the anticipated mercury vapor concentrations over time, calculated in 5 minute intervals, with the ventilation fans turned on at 0 hours and turned off at 10 hours. Note that it takes less than ½ hour at 50.5 ft/hr (equivalent to 26,000 ft^3/min active ventilation for the 1,350,000 ft^3 SRC + k_{loss}) to lower mercury vapor concentrations below levels of acute concern, but about 2 hours to reach the recommended long-term exposure concentration. Also note that when the ventilation is turned off, the mercury vapor concentration rises quite quickly. Ventilation rates of 66.5 ft/hr and 84.8 ft/hr (including a calculated loss of 15.4 ft/hr) are the calculated ventilation rates for the SRC with the fans are on full, and with fans on plus the doors are open, respectively.

Figure 1: Modeled Mercury Vapor Concentrations in SRC Gym With Different Ventilation Rates (as Turnovers per hour * Gym Height) @ 24° C (75° F)



Model Uncertainties

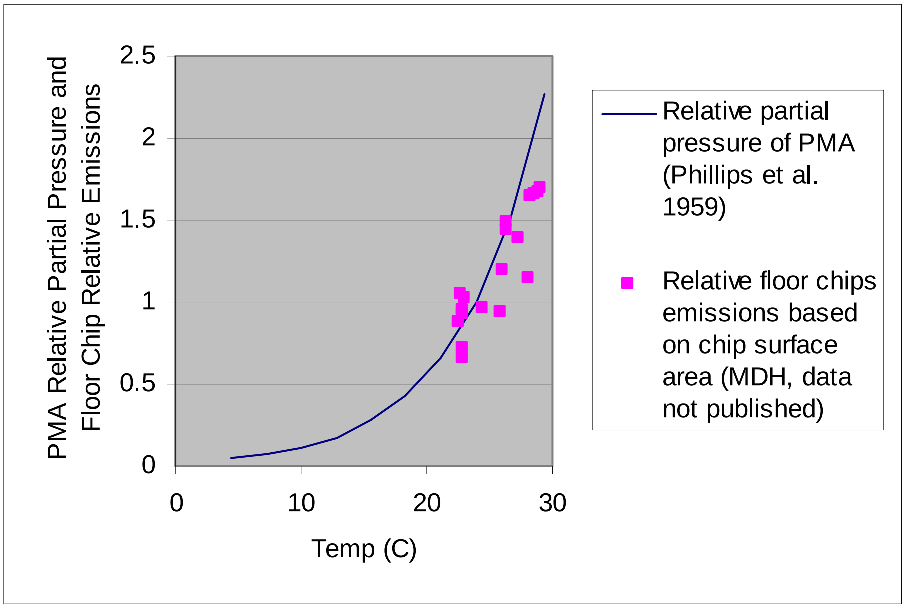
Temperature

Temperature appears to have a large impact on the emission of mercury vapor from flooring. Unfortunately, there is no published data on the impact of temperature on mercury emissions from mercury-containing floors. Phenylmercuric acetate (PMA) has been used in some mercury-containing floors and it was also used as a fungicide in some paints until this use of mercury compounds was banned in 1990 (indoor paints) and in 1991 (exterior paints) (ATSDR 1999). A study published in 1959 on the vapor pressure and saturation concentration of organo-mercuric compounds (Phillips et al.) describes the temperature dependence of PMA as:

$$\log_{10}(P) = 13.67 - 5755 / T \qquad \textit{Equation 10.}$$

where P is the partial pressure in millimeters mercury (mm Hg) and T is in degrees Kelvin (° K). Figure 2 shows the partial pressure of PMA from this relationship relative to the partial pressure of PMA at 24° C (i.e. partial pressure of PMA at 24° C set to 1).

Figure 2: Temperature Dependence of PMA Partial Pressure Relative to Partial Pressure at 24° C (1.99×10^{-6} mm Hg) and Floor Chip Emissions Relative to Floor Chip Emissions at 24° C (37.1 ng/min/ft^2)



MDH measured the emissions from chips of flooring from the SRC (data not published). Chip emissions can be calculated based on the surface area of the chip or based on the volume of the chip. If emissions, calculated as emission per chip surface area per time (ng/ft^2/min), are normalized to 24° C and then plotted against temperature, as in Figure 2, the temperature dependence appears similar to the temperature dependence of the partial pressure of PMA. Emissions appear to double for about every 5° C increase in temperature. Similar results are achieved when the emission per chip volume per time (ng/ft^3/min) is used. This demonstrates that the emissions from the flooring have a strong temperature dependence, and that this temperature dependence is similar to that of PMA.

Loss rate

One would expect there to be some air leaks in a gym. Convection currents are especially strong in large rooms, potentially increasing pressure differentials and air movement through cracks. In addition, it has been shown that mercury vapor can penetrate walls, and pass through materials like polyethylene sheets (Parker and Bloom 2005). Therefore, some unquantifiable loss of mercury vapor is expected. Forced ventilation could increase the loss by increasing pressure differentials between the inside of the building and the outside; it could decrease the loss because temperature differentials and convection air currents may create larger pressure differentials and drive air into or out of the gym; or it may have minimal impact if loss is a result of adsorption and diffusion into walls, ceilings and materials.

The model assumes that the loss is the same whether the active ventilation system is on or off. While this is probably not true, it seems a reasonable first approximation. If the model is going to be more refined, this error factor should be looked at more closely.

Loss is likely to vary widely between different gyms. Therefore, if the models developed from the SRC are used in different gyms, loss should be treated conservatively.

Decreasing mercury vapor emission rate over time

Mercury emissions are expected to decrease over time as the mercury concentration in the flooring decreases. Equation 11 can be used to calculate the concentration of mercury in the flooring at any time ($[Hg]_t$), assuming a first order process (Schwarzenbach et al. 2003):

$$[Hg]_t = [Hg]_0 * e^{-kt} \qquad \textit{Equation 11.}$$

Where $[Hg]_0$ is the mercury concentration at time 0, k is the first order rate constant (defined below), and t is time.

Equation 11 can be modified to calculate the amount of mercury in the flooring at any time by multiplying by the floor volume ($Hg_t = [Hg]_t * Vol_t$). (The amount of mercury can also be calculated from a mass-based mercury concentration.) And because the change in volume (or mass) of the flooring over time is very small:

$$Hg_t = Hg_0 * e^{-kt} \qquad \textit{Equation 12.}$$

Taking the natural log of Equation 12:

$$\ln(Hg_t) = \ln(Hg_0) - k * t$$

Then rearranging, the first order rate constant is:

$$k = \ln(Hg_t / Hg_0) / (-t) \qquad \textit{Equation 13.}$$

Rearranging Equation 13 and substituting for the special circumstance when ½ of the chemical is remaining (i.e. when $Hg_0 = 2 * Hg_t$; the half-life; $t_{½}$):

$$t_{½} = \ln(2) / k = 0.6931 / k \qquad \textit{Equation 14.}$$

Substituting the first order rate constant from equation 13 into equation 14, (assuming steady emissions, based on the concentration or amount of mercury in the flooring):

$$t_{½} = 0.6931 / (\ln((Hg_t)/Hg_0) / (-t))$$

Because the amount of mercury in the floor will, over any time period, be equal to the initial amount of mercury minus the amount of mercury emitted ($Hg_t = Hg_0 - Hg_{emit}$), the half-life of mercury in the flooring can be calculated with the equation:

$$t_{½} = 0.6931 / (\ln((Hg_0 - Hg_{emit})/Hg_0) / (-t_{emit})) \qquad \textit{Equation 15.}$$

Where:

Hg_{emit} (μg) is the amount of mercury emitted from the flooring per time period measured in minutes; t_{emit} (min).

As noted above:

$$Hg_0 = [Hg]_0 * Vol_0$$

Where:

$[Hg]_0$ is the mercury concentration in the floor (μg/ft^3) at time 0 and Vol_0 is the volume of flooring (ft^3) at time 0 (i.e. June 2006).

Using data from the analysis of a bulk floor sample (from Mercury Content of Flooring Material Section, above):

$$[Hg]_0 = 170\ \mu g/g * 2.68\ g/cm^3 * 28317\ cm^3/ft^3 = 12.9\ g/ft^3$$

For the SRC, which is 150 ft by 300 ft, and assuming that the floor is 0.0164 ft (5 millimeters) thick:

$$Vol_0 = 150\ ft * 300\ ft * 0.0164\ ft = 738\ ft^3$$

Therefore, the amount of mercury in the SRC floor in June 2006 is:

$$Hg_0 = 12.9\ g/ft^3 * 738\ ft^3 = 9.52\ kg$$

t_{emit} =1 min; the unit time that the mercury loss from the floor is measured, therefore:

$$Hg_{emit} = Hg_{in} * t_{emit} = 781.9\ \mu g$$

Where: Hg_{in} is the mercury emission rate from Controlling Mercury Vapor Concentration in Gymnasium section, above.

Substituting calculated values for Hg_0, Hg_{emit}, and t_{emit} into Equation 15 and solving:

$$t_{½} = 8.44E{+}6\ min = 16.05\ years$$

Which is the calculated half-life of mercury in the SRC floor.

It is believed that the SRC floor was installed in about 1982. Therefore, the floor is about 1.5 half-lives old.

Equation 14 can be rearranged to:

$$k = 0.6931 / t_{½}$$

and substituted into Equation 12:

$$Hg_t = Hg_0 * e^{-0.6931 * t / t½}$$

$t / t_{½}$ is equal to the number of half-lives ($\#t_{½}$) between time 0 and time t. Substituting $\#t_{½}$ and rearranging, an estimate of the initial mercury concentration can be calculated from:

$$Hg_0 = Hg_t / e^{(- \#t1/2 * 0.6931)}$$ *Equation 16.*

Assuming that the floor has been emitting from 1982 until 2006, or for 1.5 half-lives ($\#t_{½}$) and the current amount of mercury in the floor (Hg_{2006}) is 9.52 kg:

$$Hg_0 \text{ or } Hg_{1982} = 26.9\ kg$$

Or, modifying Equation 16 to calculate the starting mercury concentration in the flooring:

$$[Hg]_{1982} = [Hg]_{2006} / e^{(- \#t1/2 * 0.6931)}$$ *Equation 17.*

The mercury mass-based concentration in the chips ($[Hg]_{mass}$) was 170 ug/g in 2006. Therefore, from Equation 17:

$$[Hg]_{1982} \approx 481\ ug/g$$

According to 3M, the concentration of mercury in the mercury-containing floor they manufactured until about 20, or so, years ago was between 540 and 1000 ug/g (see Health Consultation, Table 1; Reiner 2005). This is fairly close to the calculated initial concentration, $[Hg]_{1982}$ above, but it may suggest that the data collected in June 2006 underestimates the actual emissions; or that the SRC flooring, when installed, had less mercury than the 3M formulation. There is potential for considerable error in the calculated value, given the uncertainties discussed in the above sections. However, because the emission rate was calculated from June data, one would expect that the temperature, and therefore the calculated emission rate, to be above the yearly average.

Conversely, if the range of potential concentrations in the 3M formulation are substituted into Equation 11 with SRC 2006 chip data, the calculated half-lives of the mercury in the flooring ranges from 9 to 14 years. While it is not known whether the SRC flooring was made by 3M or from a similar product, the exact year of installation, or the impact of seasonal temperature changes over the years on flooring emissions, the calculations from the SRC flooring, using a 1-compartment model, and the 3M data appear to be similar.

Using ventilation to control mercury vapor concentrations

Data shown above demonstrate that ventilation can be used to effectively decrease the mercury vapor concentration in the SRC. This has also been demonstrated in 2 other gyms in Minnesota (MDH 2006). Mercury vapor concentrations were measured by the MPCA in the Harding High School Fieldhouse on 10/21/2004 with the ventilation was off, and on 10/29/2004 with the ventilation was on. With the ventilation off the mercury vapor concentration in the gym was 1369 ng/m^3, and with the ventilation on the mercury vapor concentration decreased to 319 ng/m^3 (temperatures were not recorded). Mercury vapor concentrations in the Como Senior High School Fieldhouse were between 2400 and 3700 ng/m^3 with the doors open, but the ventilation off on 8/14/2007 (floor temperature 27-28° C); and between 140 and 312 ng/m^3 with the door closed but the ventilation running on 8/15/2007 (room temperature 23-24° C). However, unfortunately, the amount of ventilation in either of these gyms was not known. Therefore, the model shown in section “Controlling Mercury Vapor Concentration in Gymnasium” has not been verified in another gym.

References

Agency for Toxic Substances and Disease Registry (1999). Toxicological profile for mercury. Research Triangle Institute under contract no. 205-93-0606. March 1999. http://www.atsdr.cdc.gov/toxprofiles/tp46.html

Minnesota Department of Health (2006). Mercury-Containing Polyurethane Floors in Minnesota Schools: Mercury Vapor Release/Athletic Polymer Floors. St. Paul, MN. Health Consultation, Concurrence from the Agency for Toxic Substances and Disease Registry. September 28, 2006. http://www.health.state.mn.us/divs/eh/hazardous/topics/mercuryvapor.pdf

Parker, J.L. and N.S. Bloom (2005). Preservation and storage techniques for low-level aqueous mercury speciation. Science of the Total Environment 337(1): 253-263.

Phillips, G.F., B.E. Dixon and R.G. Lidzey (1959). The volatility of organo-mercury compounds. J. Sci. Food Agric 10: 604-610.

Reiner, E.A. (2005). Letter to C. Herbrandson, Minnesota Department of Health. Re: Questions About Rubber-Like Floors. 3M Environmental Health and Safety Operations, St. Paul, MN. September 23, 2005.

Schwarzenbach, R.P., P.M. Gschwend and D.M. Imboden (2003). Environmental Organic Chemistry. 2nd Edition. New York, John Wiley & Sons, Inc.