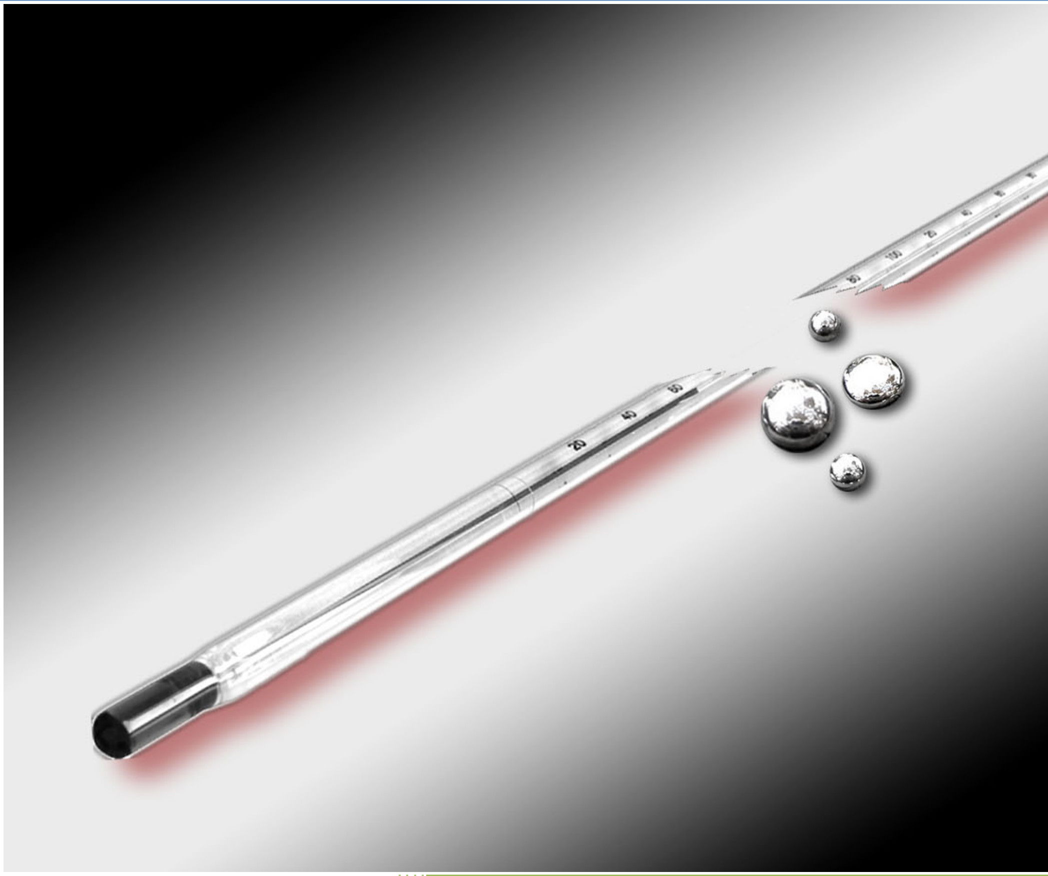
United States Environmental Protection Agency

A Guide for Federal Agencies on Replacing Mercury-Containing Non-Fever Thermometers



Office of Chemical Safety and Pollution Prevention
Publication #740B13001
June 2013
www.epa.gov

Table of Contents

I. Introduction

This guide provides federal agencies with information to help them identify and replace mercury-containing non-fever thermometers in their facilities with mercury-free thermometers. The guide is also intended to help federal agencies safely dispose of the removed thermometers. Fever thermometers are not addressed in this document.

A. Health and Environmental Issues

Elemental (metallic) mercury primarily causes health effects when it is breathed as a vapor and absorbed through the lungs. These exposures can occur when elemental mercury is spilled or products that contain elemental mercury break and expose mercury to the air, particularly in warm or poorly-ventilated indoor spaces. The factors that determine how severe the health effects are from mercury exposure include the following: the chemical form of mercury; the dose; the age of the person exposed (the fetus is the most susceptible); the duration of exposure; the route of exposure -- inhalation, ingestion, dermal contact, etc.; and the health of the person exposed.

Symptoms of exposure to elemental mercury can include these: tremors; emotional changes (e.g., mood swings, irritability, nervousness, excessive shyness); insomnia; neuromuscular changes (such as weakness, muscle atrophy, twitching); headaches; disturbances in sensations; changes in nerve responses; performance deficits on tests of cognitive function. At higher exposures there may be kidney effects, respiratory failure and death.

Mercury use in products such as thermometers can lead to releases to the environment during the manufacturing of the products; from spills and breakage during use; and during the recycling, collection and disposal of these products. Concerns about public health are primarily based on the risk of exposure due to mercury spills not cleaned up properly and from improper disposal of broken thermometers resulting in mercury releases through incineration or land application of sludge. Non-fever thermometers are widely used in industrial, laboratory or health-care settings, but in most cases effective non-mercury alternative products exist.

B. Federal Efforts

Executive Order 13514 (pdf) (11 pp, 151kb) About PDF ("Federal Leadership in Environmental, Energy and Economic Performance") encourages federal agencies to advance environmental goals including sustainable acquisition by acquiring products that are non-toxic or less toxic alternatives (www.gpo.gov/fdsys/pkg/FR-2009-10-08/pdf/E9-24518.pdf). Replacing mercury-containing non-fever thermometers with mercury-free devices is one way for federal agencies to work toward achieving this goal.

As part of efforts to reduce the use of mercury in products, the U.S. Environmental Protection Agency (EPA) is encouraging federal agencies, industry and others to phase out the use of mercury-containing non-fever thermometers. An important barrier to phase-out has been the existence of industry and government standards and test methods that specifically require laboratory and industrial mercury-in-glass thermometers. To address this technical problem, EPA has been working closely with other standards-setting organizations to help revise government test methods or standards that require the use of mercury-containing thermometers where effective and comparable mercury-free alternatives exist.

The National Institute of Standards and Technology (NIST) is the primary U.S. government agency devoted to advancing measurement science, standards, and technology. NIST has determined that there are no fundamental barriers to the replacement of mercury-containing thermometers. As a result, as of March 1, 2011, NIST no longer calibrates mercury-containing non-fever thermometers. This action provides further incentive for government agencies to switch to mercury-free thermometers.

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), develops international voluntary consensus standards, and EPA incorporates many ASTM standards into its regulations. ASTM is in the process of evaluating its approximately 839 standards that require mercury-in-glass industrial and laboratory thermometers, and has begun updating its standards to allow use of mercury-free thermometers wherever appropriate. For a list of updated ASTM standards, see ASTM Standards Permitting Use of Alternative Non-Mercury Thermometers (pdf) (7 pp, 127 kb) About PDF (www.epa.gov/hg/pdfs/astm_standards.pdf). Each time an ASTM standard referenced in an EPA regulation is updated to allow increased flexibility to use mercury-free alternatives; EPA must then update references to these methods in its regulations in order to allow a person subject to the regulation to use the updated standard to fulfill the regulation's requirements. On January 18, 2012, EPA issued a new rule (pdf) (11 pp, 198 kb) About PDF that updated references to three ASTM standards to allow the use of mercury-free thermometers in certain field and laboratory applications relevant to petroleum refining, power generation, and polychlorinated biphenyl (PCB) waste disposal (www.gpo.gov/fdsys/pkg/FR-2012-01-18/pdf/2012-712.pdf).

In 2006 EPA initiated its own internal effort to replace mercury-containing non-fever thermometers. EPA has now replaced the majority of mercury-containing non-fever thermometers in Agency labs throughout the country. Since initiating the program, EPA labs removed and safely disposed of approximately 2,000 mercury-containing non-fever thermometers. To learn more about the EPA's initiative to phase-out the use of mercury-containing non-fever thermometers in industrial and laboratory settings, visit our website (www.epa.gov/hg/thermometer.htm).

Other federal agencies have also taken steps to reduce their use of mercury-containing non-fever thermometers. For example, the National Institutes of Health (NIH) established a Campaign for a Mercury Free NIH (http://orf.od.nih.gov/environmentalprotection/mercuryfree/Pages/NIH-Mercury-Hazard-Reduction-Campaign.aspx); and, through a 2008 policy (http://oma.od.nih.gov/manualchapters/intramural/3033/index.html), created mandatory restrictions on procurement, use, and disposal of mercury. The U.S. Department of State has language in its Domestic Design Guidelines and Buildings Standards requiring that all thermostats be pneumatic (mercury-free).

Case studies regarding other government efforts to transition to mercury-free non-fever thermometers are available on the website of the Northeast Waste Management Officials' Association (NEWMOA). These case studies include mercury assessments completed by a shipyard (pdf) (5 pp, 126 kb) About PDF (www.newmoa.org/publications/mercstudies/PortsmouthStudy1.pdf), an air force base (pdf) (5 pp, 175 kb) About PDF (www.newmoa.org/publications/mercstudies/HanscomStudy.pdf), and an environmental laboratory (pdf) (4 pp, 110 kb) About PDF (www.newmoa.org/publications/mercstudies/EPALabStudy1.pdf).

C. Costs to Clean up Mercury Spills

There are significant costs when cleaning up mercury spills. Spills tend to be more costly when the mercury is widely scattered or located on porous surfaces (New York Dept. of Health, 2009). Few studies have systematically assessed the cost of cleaning up mercury spills in different settings, but case studies indicate that small mercury spills typically cost approximately $1,000; for larger spills, usually in industrial or organizational settings, the cost can be more than $5,000 (Lowell Center for Sustainable Production, 2003; U.S. EPA Region 9, 2002).

In addition to the direct costs of cleaning up a spill and disposing of mercury-containing waste, there may be other costs associated with mercury spills. For example, Kaiser Permanente suggests that for every dollar spent on a direct mercury spill response, $1.75 is incurred in costs associated with training, fines, and treatment of exposure (Galligan et al., 2003).

As mentioned earlier, health and environmental costs may also be associated with mercury spills. While few people may immediately become ill after a spill, mercury exposure can have lasting health effects (Knoblauch, 2009). Mercury vapor levels are often higher in confined rooms with mercury spills even after spill remediation, which can result in detrimental outcomes to human health and the environment (Lowell Center for Sustainable Production, 2003). In addition, a spill is more dangerous when mercury thermometers break in ovens or in incubators because mercury evaporates readily at high temperatures, which creates high mercury concentrations.

Get information on preventing and cleaning up mercury releases and spills (www.epa.gov/mercury/spills).

II. Where Mercury-Containing Non-Fever Thermometers May Be Found

Government agencies are encouraged to begin the process of phasing out mercury-containing non-fever thermometers by surveying their facilities to assess where and how many of the devices still exist. While most thermometers are found in laboratories, agencies may also find mercury-containing thermometers in other facilities. In laboratories, mercury-containing non-fever thermometers may be used in autoclaves, flash point equipment, incubators, ovens, refrigerators, and other devices, as well as for calibrating other thermometers (both mercury-containing and mercury-free). HVAC/R systems can have mercury-containing non-fever thermometers in multiple locations, including along steam and chill lines. Health clinics, including dental facilities, may have such thermometers in sterilizers or refrigeration units. Food-related facilities may have mercury-containing non-fever thermometers in refrigerators, freezers, ovens, pressure cookers, and other equipment. Finally, mercury-containing non-fever thermometers are often used in tank farms to check the accuracy of temperature devices inside liquid storage tanks.

EPA developed a sample table for surveying, tracking, and phasing out mercury-containing non-fever thermometers. A template based on this sample table is included in the appendix. Other agencies may find this useful for their own programs.

III. Examples of Mercury-Free Non-Fever Thermometers

Accurate and reliable alternatives to mercury-containing thermometers are available for most uses. In this section, seven categories of such alternatives are described. The General Services Administration (GSA) procurement website offers most types of mercury-free thermometers (www.gsaadvantage.gov/).

Note: Listing a product or website in this guide does not signify EPA's endorsement of the product or website. Accuracies listed below may vary based on the application.

A. Resistance Temperature Detectors (RTDs)

A properly chosen RTD can be used to replace almost all mercury-containing non-fever thermometers. The electrical resistance of the platinum or other metal rises as the temperature rises. The readout converts the measured resistance to indicated temperature using either a standard curve or a calibration function for the particular materials used in the probe. For high-vibration applications within the temperature range of -100 °C to 150 °C (-148 °F to 302 °F), RTDs with platinum film deposited on a ceramic chip work well (Strouse et al., 2010). For applications requiring broader temperature ranges or less uncertainty, NIST recommends wire-wound RTDs. In both cases, the sensor is typically mounted in a metal sheath (Strouse et al., 2010).

Temperature range:
RTD: -200 °C to 850 °C (-328 °F to 1562 °F)
Source: http://www.omega.com/rtd.html

Accuracy:
RTD: Grade A Tolerance = ±[0.13 +0.0017 * |t|] °C
Grade B tolerance = ±[0.25 +0.0042 * |t|] °C
Where: |t| is the absolute value of the RTD's temperature in °C.
Source: http://www.temperatures.com/sensors/csensors/resistance-temperature-detectors-tds/4/

B. Standard Platinum Resistance Thermometers (SPRTs)

A special class of highly accurate RTDs (see above), SPRTs utilize reference grade platinum wire and can cost many thousands of dollars. While not very durable, their utility over a wide temperature range and excellent accuracy can make them an important category of mercury-free thermometers for certain uses (Iman).

Temperature range:

SPRT: -259 °C to 962 °C (-434 °F to 1763 °F)
Source: (Li, 1996)

Accuracy:

SPRT: 0.001 °C (± 0.002 °F)
Source: (Li, 1996)

C. Thermistors

Thermistors work well in the range of -20 °C to 100 °C (-4 °F to 212 °F). Thermistors' probes consist of ceramic material, in contrast to the metallic probes found in RTDs. Most stable when sealed with a glass coating, thermistors are best suited for uses with a low risk of mechanical shock (Strouse et al., 2010). The electrical resistance of the blend of metal oxides in these devices decreases as the temperature increases (Strouse et al., 2010).

Temperature range:

-40 °C to 150 °C (-40 °F to 302 °F)
Source: http://www.efunda.com/designstandards/sensors/thermistors/thermistors_intro.cfm

Accuracy:

± 0.1 °C (± 0.18 °F) or
± 0.02 °C (± 0.036 °F)
Source: http://www.omega.com/prodinfo/thermistor.html

D. Thermocouples

Thermocouple temperature sensors are the preferred option for applications involving mechanical shock and vibration. These devices measure the electric potential between two dissimilar metals, which varies with temperature. The International Society for Automation (ISA) Thermocouple Types E, J, K, N and T contain base-metals and can be used to measure temperatures up to approximately 1000 °C (1832 °F). Types S, R, and B contain noble-metals and can be used to measure temperatures up to approximately 2000 °C (3632 °F). The table below provides temperature range and accuracy information for a variety of thermocouples.

Table 1.

Properties of ISA Type Thermocouples

ISA Type	Temperature Range °C		Accuracy Class One	Accuracy Class Two
	(contin-uous)	(short-term)		
E	0 to +800	−40 to +900	±1.5 between −40 °C and 375 °C ±0.004×T between 375 °C and 800 °C	±2.5 between −40 °C and 333 °C ±0.0075×T between 333 °C and 900 °C
J	0 to +750	−180 to +800	±1.5 between −40 °C and 375 °C ±0.004×T between 375 °C and 750 °C	±2.5 between −40 °C and 333 °C ±0.0075×T between 333 °C and 750 °C
K	0 to +1100	−180 to +1300	±1.5 between −40 °C and 375 °C ±0.004×T between 375 °C and 1000 °C	±2.5 between −40 °C and 333 °C ±0.0075×T between 333 °C and 1200 °C
N	0 to +1100	−270 to +1300	±1.5 between −40 °C and 375 °C ±0.004×T between 375 °C and 1000 °C	±2.5 between −40 °C and 333 °C ±0.0075×T between 333 °C and 1200 °C
T	−185 to +300	−250 to +400	±0.5 between −40 °C and 125 °C ±0.004×T between 125 °C and 350 °C	±1.0 between −40 °C and 133 °C ±0.0075×T between 133 °C and 350 °C
B	+200 to +1700	0 to +1820	Not Available	±0.0025×T between 600 °C and 1700 °C
R	0 to +1600	−50 to +1700	±1.0 between 0 °C and 1100 °C ±[1 + 0.003×(T − 1100)] between 1100 °C and 1600 °C	±1.5 between 0 °C and 600 °C ±0.0025×T between 600 °C and 1600 °C
S	0 to 1600	−50 to +1750	±1.0 between 0 °C and 1100 °C ±[1 + 0.003×(T − 1100)] between 1100 °C and 1600 °C	±1.5 between 0 °C and 600 °C ±0.0025×T between 600 °C and 1600 °C

Note: The accuracy classes are differentiated by their tolerances, which also vary by thermocouple type and temperature range. T represents temperature in degrees C.

ISA Type Thermocouple Materials:
E Chromel & Constantan (Ni-Cr & Cu-Ni)
J Iron & Constantan (Fe & Cu-Ni)
K Chromel & Alumel (Ni-Cr & Ni-Al)
N Nicrosil–Nisil (Nickel-Chromium-Silicon/Nickel-Silicon)
T Copper & Constantan (Cu & Cu-Ni)
B 70% Platinum/30% Rhodium & 94% Platinum/6% Rhodium
R Platinum & 87% Platinum/13% Rhodium (Pt & Pt-Rh)
S Platinum & 90% Platinum/10% Rhodium (Pt & Pt-Rh)
Source:
http://thermalfluidscentral.org/encyclopedia/index.php/Temperature_measurements_and_instrumentation

E. Organic-Liquid-in-Glass Thermometers

Organic-liquid-in-glass thermometers work well within the temperature range of -100 °C to 100 °C (-148 °F to 212 °F) and when an uncertainty of 0.5 °C (1 °F) is acceptable. Comprised of a glass bulb and cylinder, these simple thermometers contain a liquid such as alcohol or pentane. As the temperature within the bulb increases, the liquid expands along the cylinder. The following table compares temperature range and accuracy information for mercury and organic-liquid-in-glass substitutes.

Table 2.

ASTM Organic Liquid-In-Glass Thermometers

ASTM Mercury Thermometers	ASTM Organic Thermometers*	Temperature Range	Scale Error, Max**
5C / 5F	S5C / S5F	-38 to 50 °C (-35 to +120 °F)	0.5 °C (1 °F)
12C / 12F	S12C / S12F	-20 to 102 °C (-5 to 215°F)	0.15 °C (0.25 °F)
18C / 18F	S18C / S18F	34 to 42 °C (94 to 108 °F)	0.1 °C (0.2 °F)
22C / 22F	S22C / S22F	95 to 103 °C (204 to 218 °F)	0.1 °C (0.2 °F)
56C / 56F	S56C / S56F	19 to 35 °C (66 to 95 °F)	0.10 °C (0.20 °F)
58C / 58F	S58C / S58F	-34 to 49 °C (-30 to 120°F)	0.3 °C (0.5 °F)
59C / 59F	S59C / S59F	-18 to 82 °C (0 to 180 °F)	0.3 °C (0.5 °F)
62C / 62F	S62C / S62F	-38 to 2 °C (-36 to + 35 °F)	0.1 °C (0.2 °F)
63C / 63F	S63C / S63F	-8 to 32 °C (18 to 89 °F)	0.1 °C (0.2 °F)
64C / 64F	S64C / S64F	22 to 55 °C (77 to 131 °F)	0.1 °C (0.2 °F)
65C / 65F	S65C / S65F	50 to 80 °C (122 to 176 °F)	0.1 °C (0.2 °F)
66C / 66F	S66C / S66F	75 to 105 °C (167 to 221 °F)	0.1 °C (0.2 °F)
67C / 67F	S67C / S67F	95 to 155 °C (203 to 311 °F)	0.2 °C (0.5 °F)
91C	S91C	20 to 50 °C	0.1 °C (0.2 °F)
116C	S116C	18.9 to 25.1 °C	0.1 °C (0.2 °F)
117C	S117C	23.9 to 30.1 °C	0.1 °C (0.2 °F)
120C	S120C	38.6 to 41.4 °C	0.1 °C (0.2 °F)
130C / 130F	S130C / S130F	-7 to 105 °C (20 to 220 °F)	0.5 °C (1 °F)

*The S's preceding the thermometer numbers in this column denote the use of mercury-free organic liquid.
**Scale error is a measure of accuracy and tolerance.
Sources: ASTM Designation E1-07: Standard Specification for ASTM Liquid-in-Glass Thermometers.
ASTM Designation E2251-11: Standard Specification for Liquid-in-Glass ASTM Thermometers with Low Hazardous Precision Liquid.

F. Dial Thermometers and Bimetallic Thermometers

Dial thermometers have a wide range of uses. They feature a dial pointer attached to a temperature detector or sensor. The temperature sensor may be a metal strip with two different metals bound together in a helical structure, with each metal expanding and contracting at unequal rates corresponding to changes in temperature. This results in the metal strip curling and moving the pointer to varying temperatures. In addition, dial thermometers with fluid-filled temperature sensors are manufactured with liquids (such as proprietary organic liquids),[1] gases (such as nitrogen) or vapors (such as glycerine, silicone, or glycerine/water) as actuation materials. These actuation materials expand and contract with changes in temperature and revolve the dial pointer, similar to the way in which bimetallic strips work.

Temperature range:

-73 °C to 538 °C (-100 °F to +1000 °F)
Source: http://www.reotemp.com/pdf/card.0310.pdf

Accuracy:

± 1.0% of the device's full temperature scale, typically
Source: http://www.reotemp.com/bimetal_dial-thermometers.html

G. Infrared Thermometers

Infrared thermometers detect radiance and can be used to measure high temperatures in applications such as the processing and handling of asphalt. As the technology improves, these devices may become useful for other purposes.

Temperature Range:

-60 °C to 860 °C (-76 °F to 1580 °F)
Source: http://www.omega.com/manuals/manualpdf/M4424.pdf

Extended range:

Extended range infrared thermometers are also available, but generally more expensive.
550 °C to 3300 °C (1022 °F to 5972 °F)
Source: http://lumasenseinc.com/EN/products/infrared-thermometers-and-switches/series-140/pyrometer-impac-is-140-pb.html

Accuracy:

±1.0 °C (± 1.8 °F)
Source: http://www.omega.com/manuals/manualpdf/M4424.pdf
0.3% of measured value in °C for < 1500 °C (2732 °F)
0.5% of measured value in °C for > 1500 °C (2732 °F)

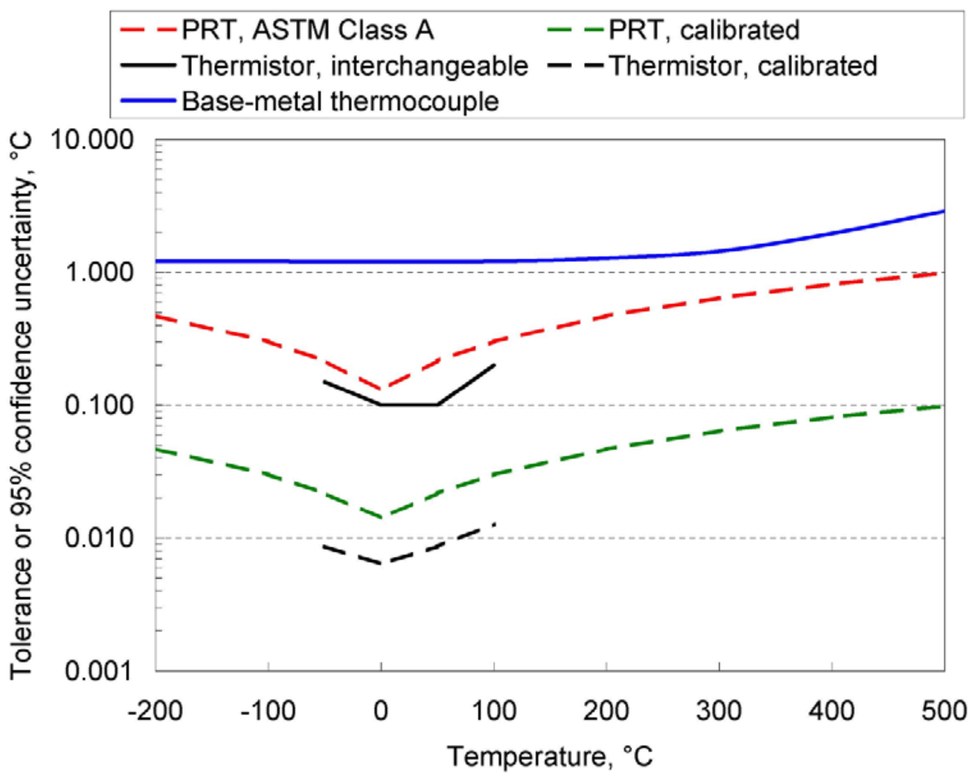
[1] Mercury is sometimes used as the actuating liquid in dial thermometers; therefore, when seeking to use dial thermometers as non-mercury alternatives, users should exercise care in avoiding mercury-filled dial thermometers.

Source:
http://lumasenseinc.com/uploads/Products/Impac/pdf/Datasheets/Pyrometer/Series_140/IS140_IGA140_PB_Datasheet.pdf

H. Comparison of Accuracies for Platinum Resistance Thermometers, Thermistors, and Base-Metal Thermocouples

Figure 1 summarizes typical manufacturing tolerances or accuracies for a variety of mercury-free thermometers in units of degrees Celsius. Low tolerance correlates to high accuracy. Calibrated thermistors have the lowest tolerance and the highest accuracy, but their temperature range is smaller than those of platinum resistance thermometers and thermocouples.

Figure 1.
Accuracies of Platinum Resistance Thermometers (PRTs), Thermistors, and Base-Metal Thermocouples with 0.001 to 10.000 Tolerances and -200 to +500 °C Temperatures



Source: Strouse et al., 2010.
Includes allowances for sensor drift and readout uncertainties.

IV. Purchasing Mercury-Free Non-Fever Thermometers

Using mercury-free thermometers in place of mercury-containing thermometers saves on the longer-term costs or life cycle costs (the cost of a thermometer from purchase to disposal). Choosing to use mercury-free thermometers also reduces the risk of exposures to mercury due to potential mercury spills. While the purchase cost of a mercury-free thermometer can be higher, that cost does not reflect the full life cycle cost of a mercury-containing thermometer because (1) if the thermometer were to break, a cost would be incurred for spill clean-up, and (2) at the end of the thermometer's useful life, a cost would be incurred to properly dispose of the mercury thermometer. Therefore, the life cycle costs, including cleaning up mercury spills, and the training, compliance, and liability associated with preventing or addressing those spills, as well as disposing of the mercury-containing thermometers are likely to be more expensive in the long run. Considering these potentials costs, many organizations see a mercury-free purchasing policy as the best economic policy (Health Care Without Harm).

Mercury-free thermometers are becoming more competitive in purchase price as market demand increases. U.S. EPA compiled Table 3 (below) based on costs for several types of thermometers available at www.gsaadvantage.gov.

Table 3: Cost Comparison between Mercury-Containing and Mercury-Free Thermometers

Thermometers	Price Range	Average Price
Mercury-in-Glass Thermometers	$24.35 to $34.58	$29.47
ASTM Certified/Calibrated	$255.35 to $461.22	$358.29
Organic Liquid-in-Glass Thermometers	$7.62.00 to $86.20	$46.91
ASTM Certified/Calibrated	$216.25 to $1,345.38	$780.82
Resistance Temperature Detectors (RTDs) (hand-Held)	$50.37 to $594.08	$322.23
Calibration/Multitasking[2]	$288.99 to $1593.13	$941.06
Probes	$11.61 to $240.99	$136.80
Thermistors (Hand-Held)	$35.57 to $427.12	$231.35
Calibration/Multitasking	$921.50 to $5,545.86	$3233.68
Probes	$8.21 to $29.60	$18.91
Probe (Certified)	$986.96	$986.96
Thermocouples (Hand-Held)	$18.25 to $446.07	$232.16
Calibration/Multitasking[2]	$186.63 to $3,387.90	$1787.27
Probes	$11.57 to $477.33	$244.45
Dial Thermometer (Bimetal/General)	$1.25 to $322.01	$161.53
Vapor/Gas Actuated	$17.38 to $380.83	$199.11
Infrared Thermometers (General Purpose)	$27.68 to $1,399.89	$713.79
Calibration/Multitasking	$1,8171.49 to $7,912.80	$13,042.15
Standard Platinum Resistance Thermometers	Range not available[1]	

[1]Available in the market for about $4,500 or more.

[2]Multitasking includes: Thermometer/transducer w. 4 to 20 mA output; Temperature Reference Kit; Intrinsically Safe feature; Thermometers with multiple probes; Calorimetric Thermometer.

V. Disposing of Mercury-Containing Non-Fever Thermometers

Once your Agency decides to replace and dispose of mercury-containing non-fever thermometers, they are hazardous waste that is regulated under federal and sometimes state laws. Under the federal Resource Conservation and Recovery Act (RCRA), mercury-containing equipment, such as thermometers, can be managed according to standards for hazardous waste or by an alternative set of standards for what is known as universal waste. EPA established alternative standards to make it easier to collect mercury-containing equipment and other universal wastes for recycling or disposal. They require that people handling this equipment prevent releases to the environment by following specified procedures, such as placing it in labeled, sturdy, closed containers that do not leak. The federal universal waste regulations can be found at 40 CFR Part 273.13(c) and 273.33(c). See additional information (www.epa.gov/epawaste/hazard/wastetypes/universal/mce.htm).

Some federal agencies have existing arrangements for managing universal wastes such as spent batteries, fluorescent light bulbs, or other mercury or non-mercury wastes. Thermometers can be managed along with these other universal wastes; often this means the wastes are collected by or taken to a waste management or environmental services company. The procedures of one federal agency are available here (http://oma.od.nih.gov/manualchapters/intramural/3033/index.html). If your Agency does not already recycle mercury items, you can find a list of mercury recyclers at Earth911.org. Note that if a mercury-containing device is broken and the mercury is loose, it can no longer be managed as universal waste and must be managed under the RCRA hazardous waste regulations. Agencies that generate hazardous wastes sometimes have existing arrangements (e.g. a contract with a waste management provider) to comply with the RCRA regulations, and thermometers could be added to those hazardous wastes. The RCRA requirements for generators of hazardous waste are found at 40 CFR Part 262.

State regulations may be more stringent or broader in scope than the federal RCRA waste management program and may vary from state to state. Agencies are encouraged to contact their state environmental regulators for more information on requirements applicable in a particular state. Read more about state-specific requirements (www.epa.gov/epawaste/hazard/wastetypes/universal/statespf.htm).

VI. References

eFunda. Introduction to thermocouples – overview. Retrieved from http://www.efunda.com/designstandards/sensors/thermocouples/thmcple_intro.cfm.

Galligan, C., Morose, G. & Giordani, J. (2003). An investigation of alternatives to mercury containing products. University of Massachusetts. Retrieved from http://www.sustainableproduction.org/downloads/An%20Investigation%20Hg.pdf.

Health Care Without Harm. Mercury-free medical devices: affordability. Retrieved from http://www.noharm.org/seasia/issues/toxins/mercury/alternatives.php.

Knoblauch, J. (2009). Dangerous mercury spills still trouble schoolchildren. *Scientific American*, *10*. Retrieved from https://www.scientificamerican.com/article.cfm?id=mercury-spills-trouble-schoolchildren.

Iman, S. Why did my temperature sensor fail calibration? Fluke Corporation. Retrieved from http://us.flukecal.com/literature/articles-and-education/temperature-calibration/papers-articles/why-did-my-temperature-sen.

Li, Xumo. (1996). Producing the highest accuracy from SPRTs. Hart Scientific. *Measurement and Control*. Retrieved from http://us.flukecal.com/category/literature-type/articles-and-education.

New York State Dept. of Health. (2009). Mercury spill incidents – data and resources. Retrieved from http://www.health.ny.gov/environmental/chemicals/hsees/mercury/mercury_spill_incidents.htm.

Strouse, G., Cross, D., Miller, W., & Ripple, D. (2010). User-friendly guidance on the replacement of mercury thermometers. Environmental Protection Agency and the National Institute of Standards and Technology. Retrieved from http://www.epa.gov/hg/pdfs/nistuserfriendlyguide.pdf

Lowell Center for Sustainable Production. (2003). Mercury spills – how much do they cost. Retrieved from http://www.sustainablehospitals.org/PDF/IP_spills_cost.pdf.

U.S. EPA Region 9. (2002). Eliminating mercury in hospitals. Retrieved from http://www.epa.gov/region9/waste/p2/projects/hospital/mercury.pdf.

Appendix

Sample Table for Tracking Mercury-Containing Thermometers

Location	Contact	Number of Mercury-Containing Thermometers:		Detailed Information About the Remaining Mercury-Containing Thermometers:				Additional Information:	Barriers/Limitations That Impede the Use of Non-Mercury Alternatives:				
		Removed from Service in [YEAR]	Present at the End of [YEAR]	Brand/Manufacturer Name and Model Number or ASTM Number	Quantity	Primary Use or Application	Is Substitution Possible? (Explain)		Regulations	Method Parameters	ASTM or External Standards	Lack of Alternative	Technical/Physical Limitations