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CANDLES AND INCENSE AS
POTENTIAL SOURCES OF
INDOOR AIR POLLUTION:
MARKET ANALYSIS AND
LITERATURE REVIEW

Prepared for

Office of Research and Development

Prepared by

National Risk Management
Research Laboratory
Research Triangle Park, NC 27711

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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CANDLES AND INCENSE AS POTENTIAL SOURCES OF INDOOR AIR POLLUTION: MARKET ANALYSIS AND LITERATURE REVIEW

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Abstract

The report summarizes available information on candles and incense as potential sources of indoor air pollution. It covers (1) market information and (2) a scientific literature review. The market information collected focuses on production and sales data, typical uses in the US, and data on the sources and quantities of imported products. The estimated total sales of candles in 1999 varied between $968 million and $2.3 billion, while imports were $486 million. The US imports and exports of incense in 1999 were $12.4 and 4.6 million, respectively. The scientific literature review gathered information regarding the emission of various contaminants generated when burning candles and incense, as well as the potential health effects associated with exposure to these contaminants. Burning candles and incense can be sources of particulate matter. Burning candles with lead core wicks may result in indoor air concentrations of lead above EPA-recommended thresholds. Exposure to incense smoke has been linked with several illnesses, and certain brands of incense also contain chemicals suspected of causing skin irritation.

Table of Contents

Tables

1. Findings

The purpose of this report is to collect economic information regarding the production and sales of candles and incense in the US, including information about imports. A second objective is to review the scientific literature regarding emission rates and potential human health effects associated with burning candles and incense. The following is a brief overview of the findings.

1.A Economic Data on Candle and Incense Production and Sales

- The Census Bureau reports 107 manufacturing establishments; however, industry estimates range from 160 to over 200 manufacturers. Many manufacturers are very small.

- Candle sales have been growing rapidly in the last 10 years (10 to 15 percent per year), fueled by consumer interest in aroma therapy and increased demand for home fragrance products in general.

- The Census Bureau reports a total value of shipments in 1997 of $968 million; industry estimates put 1999 sales at $1.3 billion just for scented candles, and up to $2.3 billion for all candles.

- The top five countries that export candles to the US are China, Taiwan, England, Hong Kong, and Mexico.

- There are no public data on incense manufacturers; private data show at least 26 manufacturers. Limited discussions with some industry representatives indicate that there are probably many more very small manufacturers.

- The top five countries that export incense to the US are India, China, Thailand, Japan, and Hong Kong.

1.B POTENTIAL INDOOR AIR QUALITY IMPACTS OF BURNING CANDLES AND INCENSE

- Burning candles containing lead core wicks can result in indoor air concentrations of lead above EPA-recommended thresholds.

- In the scientific literature we reviewed, zinc and tin were found not to be emitted at concentrations that would raise concerns when burned indoors.

- One study showed worst-case scenario concentrations of acrolein, formaldehyde, and acetaldehyde from candle emissions exceeding EPA-recommended thresholds.

- Sooting can occur when combustion conditions are impaired when burning candles. Scented candles are more likely to produce soot than unscented candles. Sooting can cause property damage by blackening surfaces. We could not identify any studies on potential human health effects associated with soot from candles.

- Several studies indicated links between exposure to incense smoke and health effects, including cancers and contact dermatitis. A few studies indicated possible mutagenic and genotoxic effects.

- Studies that examined the emissions of specific contaminants from incense smoke indicated that benzene and particulate matter may be emitted at concentrations that could pose human health risks.

2. BACKGROUND

The potential indoor air impacts of burning candles and incense have drawn increased attention in recent years. For example, candles with lead wicks have been found on the market and have been shown to emit lead when burned. Sooting associated with burning candles can cause property damage by blackening walls, ceilings, and carpets. Incense smoke can be a major source of particulates in indoor air. Emissions from incense may contain contaminants that can cause a variety of health effects.

EPA is currently testing the emissions from candles and incense to generate data for analyzing risk management options. To support this effort, this report collects and presents information on the production and sales of candles and incense, the sources and quantities of imported products, and the typical product uses in the US. This information will help EPA in assessing the nature and extent of human exposure. In addition, this report summarizes the results and findings in the scientific literature regarding the emission rates of the various contaminants generated when burning candles and incense, as well as the potential health effects associated with exposure to these contaminants. EPA will use this information to further their research and understanding of the potential impacts of these sources on indoor air quality.

3. ECONOMIC DATA ON CANDLE AND INCENSE PRODUCTION AND SALES

3.A CANDLES

A variety of candle types are manufactured in the US, including tapers, straight-sided dinner candles, spirals, column, votives, tealights, wax-filled containers, and novelties. Some are scented and all come in a wide range of colors. Wax candles contain petroleum wax, vegetable wax, animal wax, or insect wax as the primary fuel. The wax may contain additives for color, fragrance, stability, or to modify the burning characteristics.

Gel candles use liquids such as mineral oil, terpene-type chemicals, or modified hydrocarbons as their primary fuel. These candles also contain chemical agents to increase the viscosity of the fuel to the point where the candle has a quasi-rigid property.

Candles support one or more combustible wicks. Metal is put in some wick cores to keep the wick standing straight when the surrounding wax begins to melt. The metal prevents the wick from falling over and extinguishing itself as soon as the wax fails to support it. Many companies use a braided wick, which consists of three smaller wicks wound together to provide some stiffness.

Lead was commonly used as a core material until 1974 when the US candle manufacturing industry voluntarily agreed to discontinue use of lead in wicks. There are, however, still candles on the market that contain lead wick cores. Most of these are imported. Zinc is commonly used as an alternative metal core for the wicks, since it provides the desired amount of stiffness, burns off readily with the rest of the wick, and the airborne particles from zinc wicks are considered safer.[1]

Scented candles have grown in popularity and are widely used. The majority of candle manufacturers offer scented candles. Seventy-five percent of the manufacturers who are members of the National Candle Association (NCA) listed fragranced candles among the types of candles they produce. Forty percent say they manufacture citronella candles (NCA, 1999). Citronella is an insect repellant.

Number of Candle Manufacturers

The candle industry is a relatively small industry and does not have an abundance of publicly available data. The 1997 Economic Census published by the US Census Bureau reports 107 manufacturing establishments with a primary North American Industry Classification System (NAICS) product classification code of 3399995, defined as "candles, including tapers" (US Census Bureau, 1999). These establishments collectively employed 8,536 workers. The Census Bureau has very limited data available since the industry is identified at the 7-digit level.

ERG conducted an online search of the Thomas Register of American Manufacturers. This

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[1]Telephone communication between Marianne McDermott, Executive Vice President, National Candle Association, and Lynn Knight, ERG, August 18, 2000.

search identified 160 candle manufacturers. However, the National Candle Association (NCA) estimates there are over 200 known commercial, religious, and institutional manufacturers of candles in the US, as well as many small craft producers (NCA, 1999). The NCA reports that 70 of their members are manufacturers and represent roughly 80 percent of the market. The three largest publicly traded manufacturers are Candle Corporation of America, Candle-Lite, Inc., and The Yankee Candle Company, Inc. (NCA, 1999). A Merrill Lynch Global Securities analyst reported that Yankee Candle Co. accounts for about 10 percent of industry sales. It has 100 stores and plans to open 40 per year (Fort Worth Star-Telegram, 1999).

A private market study by the Packaged Facts group reports that the candle industry is not only growing, but is undergoing some consolidation. This trend is not limited to smaller companies, but has included some of the leading manufacturers and marketers succumbing to stronger, better financed companies (Packaged Facts, 1999). This source believes that company buyouts are motivated by parent organizations attracted to making acquisitions in a thriving market and then helping these acquisitions grow their product lines and increase market share. For example, Yankee Candle's partnership with Forstmann Little was reportedly undertaken specifically to fund a major expansion (Packaged Facts, 1999).

Internet sales of candles have been increasing. Many smaller candle companies are emerging and doing well selling their products on the Internet, as the appearance of prominence can be obtained with a nice looking Web site. Selling on the Internet allows these manufacturers to sell candles at a reasonable price, since they can pass on savings accrued by avoiding middlemen, slotting fees paid to retailers, and advertising costs (Packaged Facts, 1999).

There have been many types of new entrants to the growing candle market. Market research analysts believe that new marketers are attracted to this burgeoning market because candles are relatively simple to make, color, and fragrance, and novelty designs easily attract the buyer's attention (Packaged Facts, 1999). The scented candles market has seen a lot of cross-category encroachment, as fashion designers, perfume manufacturers, and specialty chain marketers introduce their own lines of candles. For example, upscale retailers, such as The Gap, Pottery Barn, Pier One, and the Bombay Company, are marketing scented candles under their own trademark. SC Johnson, too, began selling candles fragranced with many of Glade's air freshener trademark scents (Packaged Facts, 1999). Meanwhile, dedicated candle outlets, like Yankee Candle, White Barn Candle Company, and Illuminations, are expanding throughout the US (Packaged Facts, 1999).

Sales

The 1997 Economic Census reports a total value of shipments for candle manufacturers of $968.3 million. Companies with shipments of $100,000 or more accounted for 98 percent of shipments, or $951 million. In 1992, shipments for these larger companies were $366 million. The value of shipments increased more than 2.5 times over this 5-year period.

The NCA states that the US candle consumer retail sales for 1999 are reported at $2.3 billion, not including candle accessories. NCA further reports that sales of all candles (unscented, scented, and for institutional and religious uses) have been growing 10 to15 percent a year since 1990[2] (NCA, 1999). The Packaged Facts report claims that the growth of scented candles alone is close to 22 percent per year. This same report estimates that scented candles represent 55 percent of the $2.4 billion total home fragrance market, or $1.3 billion in scented candle sales. Another source, The Freedonia Group, estimated that 1999 candle sales were $1.17 billion.[3]

Unity Marketing, another private marketing research firm, conducts annual surveys among gift manufacturers who produce and market candles and candle accessories. The most recent survey, which had 37 respondents, was conducted in 2000 and covered 1999 sales. The survey results showed an upward trend in total annual sales for 1999, with average company sales among respondents up 39 percent from $10 million in 1997 to $14 million in 2000. In 1999, 39 percent of companies surveyed reported annual sales of more than $10 million as compared with only 27 percent in 1997. (See Table 1.)

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[2] The source of these estimates is not disclosed in the NCA publication.
[3] This figure was interpreted from the Freedonia Group's prediction that sales would increase 8.1 percent annually to reach $1.6 billion in 2003.

Table 1: Total Sales of Candle Companies in 1999

Total Annual Sales (Dollars in Thousands)	Percent of Candle Companies Surveyed[a]
> $50,000	12
$26,000 - $50,000	9
$11,000 - $25,000	18
$6,000 - $10,000	9
$1,000 - $5,000	27
$500 - $999	15
<$500	12

[a]These statistics do not cover only candle manufacturing. They include manufacturers of candle accessories as well. Fifty-three percent of companies surveyed owned their own factory facilities. Figures do not add to 100 percent.
Source: Unity Marketing, 2000.

Candles are sold through a variety of distribution channels. According to the Unity Marketing survey, specialty retail stores capture a large portion of candle sales. (See Table 2.) Packaged Facts estimates that 51 percent of 1998 scented candle sales were attributable to mass merchandisers, 36 percent to supermarkets, and 13 percent to drug stores. (Unity Marketing and Packaged Facts each based their estimates on different distribution channel categories, thus not allowing direct comparisons.)

Table 2: Percent of Candle Sales by Distribution Channel

Distribution Channel	Percent of Total
Specialty Retail Stores (gift, card, collectible, and decorative accessory shops)	68
Department Stores	9
Mass Merchandisers and Discounters	8
Internet	4
Consumer Direct Marketing (catalogs, direct response ads, or promotional mailings)	4
Other	7

Source: Unity Marketing, 2000.

Market Trends

In their reporting of product statistics, the Economic Census reports nearly a doubling in the number of candle manufacturers from 1992 to 1997. As discussed above, recent years have shown new entrants to the candle manufacturing industry. Although many new manufacturers have entered the market, according to a the Unity Marketing survey, the majority (75 percent) of gift manufacturers that produce and market candles and candle accessories have been in the business for a long time. Half of the companies in the survey have been in business for 11 to 25 years, while another 25 percent have been in business longer.

The NCA reports that, in the last 5 years, the industry has doubled its sales. Trade association sources as well as numerous trade publication articles attribute this tremendous growth to the rapid increase in sales of aroma therapy and other scented candles. A supermarket trade publication reported that in 1999, candles were generating annual sales increases of around 20 percent (Supermarket News, 1999). The same publication states that retailers and suppliers attribute the upswing in sales to the fact that consumers view candles as a relatively cheap and accessible fashion accessory for the home for special events or seasonal decoration, or just as an accessible means of augmenting the atmosphere within the home.

Shipments of candles are forecast by the Freedonia Group, a private research firm, to expand 8.1 percent per year reaching $1.6 billion in 2003 (The Freedonia Group, Inc., 1999). They predict that, in addition to the mature market for ceremonial and utilitarian lighting applications, introduction of numerous fashion-driven, upscale offerings and mood-enhancing scented varieties, will spur gains; as will the increasing market presence of candle-only stores. Supermarkets, drug store chains, and upscale department stores have all expanded their candle offerings, including displays in multiple departments, such as air-freshener, body/bath sections, and health and beauty products displays.

The Freedonia Group report predicts that the pace of growth will slow from the double-digit increases of the earlier decade, due to increased competition from imports and some loss of consumer interest. This is in contrast to the Packaged Facts report that observes that, even though the trade press has previously reported that the popularity of candles and potpourri usually alternates on a 5-year cycle, candles are continuing to sell beyond that cycle and are showing no signs of slowing down.

Another business publication reports that candles are the largest growing segment in the giftware market. Sales have been buoyed by the introduction of high-fashion candle stands and display accessories as well as innovations in candle design, shape, color, and fragrances. Longer lasting scents and unique decorative styles have attracted buyers. Females between the ages of 25 and 54 with household annual incomes over $25,000 are the prime market. Men purchase candles at about half the rate of women (Business Wire, 1999).

Sources of Imported Candles

The Census Bureau tallies import data from the various ports of entry by originating country. These data show that in 1999, China, Hong Kong, Mexico, and Canada were the largest suppliers of candle imports. (See Table 3.) A total of 197.9 million kg of candles valued at $484.2 million were imported in 1999. The Freedonia Group reports that candle imports more than tripled between 1993 and 1998.

Unity Marketing investigated the sources of imports when surveying candle manufacturers. (See Table 4.) This survey showed that 68 percent of companies reported China as the top country supplying imported candles.

Table 3: 1999 Candle Imports[a]

Country of Origin	Quantity (kg)	Percent of Total	Custom Value
China	68,922,143	34.8	$131,759,756
Hong Kong	26,506,500	13.4	$53,548,145
Mexico	25,449,253	12.9	$50,868,810
Canada	24,781,312	12.5	$73,683,421
Guatemala	8,529,417	4.3	$55,737,602
Israel	8,395,482	4.2	$19,425,929
Thailand	7,532,504	3.8	$18,439,677
Taiwan	6,876,205	3.5	$17,525,569
Italy	4,722,934	2.4	$13,162,283
El Salvador	2,594,292	1.3	$3,332,61
Macao	2,227,634	1.1	$4,474,057

[a]Table includes data only from countries supplying 1 percent or greater of the total quantity of imports.
Source: US Bureau of the Census, 2000.

Table 4: Sources of Imported Candles in 1999

Country	Percent of Companies Surveyed
China	68
Taiwan	40
England	36
Hong Kong	36
Mexico	36
Philippines	25
Thailand	25
Indonesia	21
France	18
Italy	18
Malaysia	18
Germany	14
Japan	14
Spain	11
Australia & New Zealand	7
Ireland	7
Poland	7
India	7
Brazil	4
Canada	4
Singapore	4
Other	7

Source: Candle Report, Unity Marketing, 2000.

Product Use in the US

Candles are purchased for utilitarian, religious, or other institutional purposes, but the majority of candles, particularly scented candles, are purchased for non-utilitarian home use. Consumers buying scented candles derive utility from the decorative and aromatic attributes of the candles. The NCA reports that 7 out of 10 US households use candles, and candle manufacturers' surveys show that 96 percent of all candles purchased are bought by women (NCA, 1999).

Some candles are purchased for special events, such as parties, or for seasonal decorations. Thus candle sales do especially well in parts of the country that experience four seasons. Impulse buying accounts for a significant portion of purchases on a regular basis because people are attracted to the scent when they encounter candles while shopping (Supermarket News, 1999). People encounter candles more often as supermarkets, drug stores, and mass-merchandisers increase their candle offerings. Candles are sold alongside floral and gift merchandise, as well as greeting cards. Candles for home decorating and fragrance have broad appeal, crossing all demographic lines (Supermarket News, 1999). The NCA reports that seasonal (e.g., Christmas and other holidays) buying accounts for roughly 35 percent of sales (NCA, 1999).

3.B INCENSE

Incense has been used for centuries for ceremonial purposes as well as to fragrance the environment, conceal undesired ambient odors, or freshen clothing. Most incense is made from a combination of fragrant gums, resins, woods, and spices. One traditional method of making incense is to prepare a paste of pulverized botanicals, water, and charcoal and wrap the paste around a bamboo twig. After the twig dries, it is dipped into perfumed essential oils or powders. Incense is available in sticks, cones, rods, coils, small blocks, wands, and powders (Packaged Facts, 1999).

The US Census Bureau does not maintain data to the level of detail required to capture incense manufacturers. Economic data for incense manufacturers are aggregated under NAICS material code 325998, which is defined as *other miscellaneous chemical products, manufacturers of chemical preparations not elsewhere classified, including essential oils*. This category covers production of all types of essential oils, pyrotechnics, fireworks, drilling muds, and other industrial preparations, such as foundry and rubber processing supplies. ERG was unable to find a detailed source of government data covering specifically incense manufacturing and sales.

The Thomas Register of American Manufacturers on-line database lists 26 companies as manufacturers of incense. After contacting nine of the companies listed, we were able to find very little additional information about incense manufacturing in the US. One company representative said that many companies listed as manufacturers may indeed be repackagers who import incense and repackage it for sale in the US. Another stated that there are many domestic manufacturers that are very small—possibly single individuals making incense for sale locally. One manufacturer contacted claimed they had $500,000 in annual sales.

The US Census Bureau data on domestic exports for 1999 show a total value of $4.6 million for incense. This figure represents total exports worldwide. The highest percentages of exports went to Canada, followed by Mexico, the United Kingdom, and Japan. Quantities (weight) of exports were not reported.

The Census Bureau also reports data on imports of incense to the US. In 1999, $12.4 million of incense was imported to the US. The largest percentage of imports came from India, followed by China, Thailand, and Japan. (See Table 5.)

Table 5: 1999 Imports of Odoriferous Preparations Which Operate By Burning

Country of Origin	Value of Imports	Percent of Total
India	$3,308,591	26.7
China	$2,290,454	18.5
Thailand	$2,178,078	17.6
Japan	$1,645,833	13.3
Hong Kong	$891,850	7.2
United Kingdom	$549,540	4.4
Mexico	$507,586	4.1
Other[a]	$459,572	3.7
France	$450,941	3.5
Vietnam	$126,002	1.0
Total World	$12,408,447	100

[a]Countries each supplying less than 1 percent of imports, including Canada, The Netherlands, Belgium, Germany, Italy, Greece, Syria, Israel, Saudi Arabia, Pakistan, Nepal, Burma, Indonesia, Macao, Korea, Taiwan, Australia, Egypt, and Ethiopia.
Source: US Census Bureau

Given that $12.4 million worth of incense is imported to the US, and $4.6 million is produced domestically for export, the US market for incense is at least $17 million, excluding the value of what is produced domestically for domestic consumption.

Descriptive literature on the incense industry is very limited. Only one article was found despite a thorough search of market literature databases. This article discussed the incense manufacturing industry in Japan. It reported that the largest Japanese manufacturer of incense is Nippon Kodo Co. Ltd., who manufactures more than 2,000 fragrance products made from natural materials. One-third of its annual turnover is derived from overseas markets, including Europe and the US. Company officials claim they control more than 50 percent of the incense market in the country. The company has six plants in Japan, one in Taiwan, and one in Hong Kong and imports its raw materials from Vietnam and Indonesia. This year, the company began distributing incense in Malaysia to satisfy the increasing demand for environmentally friendly incense for religious, home fragrance, and anti-stress purposes (Bernama, 2000).

4. Potential Indoor Air Quality Impacts of Burning Candles and Incense

4.A Candles

When candles are burned, they emit trace amounts of organic chemicals, including acetaldehyde, formaldehyde, acrolein, and naphthalene (Lau et al., 1997). However, the primary constituent of public health concern in candle emissions is lead. Metal was originally put in wicks to keep the wick standing straight when the surrounding wax begins to melt. The metal prevents the wick from falling over and extinguishing itself as soon as the wax fails to support it. The US candle manufacturing industry voluntarily agreed to cease production of lead-containing candles in 1974, once it was shown that burning lead-wick candles resulted in increased lead concentrations in indoor air (Sobel et al., 2000b). Unfortunately, despite the voluntary ban, lead wick candles can still be found on the market.

According to the National Candle Association (NCA), most US candle manufacturers have abided by the agreement to cease lead wick production. All of the NCA members have signed pledges not to use lead wicks in candles they manufacture. In addition, the NCA has sent a letter to all the candle manufacturers registered with the Thomas Register of American Manufacturers informing them of the potentially adverse health effects associated with wicks that contain lead and asking them to sign pledges not to use wicks containing lead in their candles. The NCA has also sent letters to retailer trade associations to inform them of this issue.

The NCA states that only a small number (one or two) of candle manufacturers make their own wicks. The rest purchase wicks from wick manufacturers. One such manufacturer is Atkins and Pearce, Inc.; they claim to have stopped making and selling wicks with lead in 1999.

The Candle Product Subcommittee of the American Society of Testing and Materials (ASTM) is working on voluntary standards for candle content, including labeling standards. It is anticipated that this standard will address the lead issue. The draft standard was presented at the fall 2000 ASTM meeting.

There have been limited investigations regarding the prevalence and source of candles with lead wicks. ERG did not find any statistical studies investigating the presence of lead-wick candles in the US marketplace. However, a handful of studies contain some information about the occurrence of lead-wick candles in the local study areas. The following discussion and Table 6 present information on lead and other chemicals emitted from candles.

Lead Wick Emissions

In February 2000, the Public Citizen's Health Research Group conducted a study of the lead content of candles in the Baltimore-Washington area. They purchased 285 candles from 12 stores, excluding candle-only stores, and tested the wicks for the presence of lead. They found that nine candles, or 3% of the candles they purchased, contained lead. Total lead content ranged from approximately 24,000 to 118,000 μg (33 to 85% of the weight of the metal in the candle wick).

An academic study was conducted on the emissions of lead and zinc from candles with metal-core wicks (Nriagu and Kim, 2000). For this study, the researchers purchased and tested candles (found in Michigan stores) that had metal-core wicks. Fourteen brands of candles manufactured in the US, Mexico, and China were found to contain lead. Emission rates from candles ranged from 0.52 to 327 μg-lead/hour, resulting in lead levels in air ranging from 0.02 to 13.1 $\mu g/m^3$. These concentrations are below the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit[4] (PEL) of 50 $\mu g/m^3$, but above the EPA outdoor ambient air quality standard[5] of 1.5 $\mu g/m^3$. It is important to note that, although the EPA standard was not developed for use for indoor air comparisons, it is used throughout this report as a conservative comparison value. OSHA's PEL values should also be interpreted with some caution for they are occupational standards not designed for the protection of the general public, children, or sensitive populations.

Another prominent study, van Alphen (1999), examined emissions and inhalation exposure-based risks for candles having lead wick cores. The mean emission rate was 770 μg-lead/hour, with a range of 450 to 1,130 μg-lead/hour. A candle burned for 3 hours at 1,000 μg-lead/hour in a 50 m^3 room with poor ventilation is estimated to yield a 24-hour lead concentration of 9.9 $\mu g/m^3$, and a peak concentration of 42.1 $\mu g/m^3$. OSHA's 50 $\mu g/m^3$ PEL is not approached in this

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[4]PEL (Permissible Exposure Limit): These OSHA standards were designed to provide health protection for industry employees by regulating exposure to over 300 chemicals. PELs are an 8-hour time weighted average.
[5]EPA Outdoor Ambient Air Quality Standards: Required by the Clean Air Act, these standards were set for pollutants thought to harm public health and the environment, including the health of "sensitive" populations such as asthmatics, children, and the elderly.

study, but again, EPA's outdoor ambient air standard of 1.5 $\mu g/m^3$ is exceeded.

Sobel et al. (2000a) modeled lead emissions from candles containing lead wicks. After burning multiple candles in a contained room, 24-hour lead concentrations ranged from 15.2 to 54.0 $\mu g/m^3$. The candle containing the least amount of lead produced lead concentrations of 30.6 $\mu g/m^3$ in 3 hours. The maximum concentration of 54 $\mu g/m^3$ is above the PEL standard of 50 $\mu g/m^3$ and EPA's outdoor ambient air quality standard of 1.5 $\mu g/m^3$.

Other Metals

Zinc

After the ban on lead-containing wicks, candle companies began looking for alternatives that provided the desired characteristics of the lead wick without the harmful emissions. Many companies turned to braided wicks, which consist of three smaller wicks wound together to provide some stiffness. Zinc cores are also commonly used, since the metal provides the desired amount of stiffness, burns off readily with the rest of the wick, and does not have the same toxic effects as lead.

Zinc is an essential element for human health. However, inhaling large amounts of zinc (as zinc dust or fumes from smelting or welding) over a short period of time (acute exposure) can cause a disease called metal fume fever. Very little is known about the long-term effects of breathing zinc dust or fumes (Eco-USA.net, 2000).

Nriagu and Kim (2000) found the release of zinc from metal-core wicks to be 1.2 to 124 μg/hour, which is too low to be of health concern in indoor air. All nonferrous metals have traces of lead impurities; for zinc, the maximum lead content is 0.004% (Barker Co., 2000). The lead emissions from zinc wicks are below the detection level of most test methods (Barker Co., 2000), though one study found emission rates of 0.014 μg-lead/hour (Ungers and Associates, 2000).

Tin

Tin is also commonly used as a stiffener for candle wicks. It is considered to be nontoxic (Chemglobe, 2000). Tin has a maximum lead content of 0.08%, but, like zinc, lead emissions are below the detection limit when tin wicks are burned (Barker Co., 2000).

Organics

Several organic compounds have been detected in candle emissions. Three articles have focused specifically on this topic. Lau et al. (1997) measured levels of selected compounds in candle materials and modeled human exposure to a worst-case scenario of 30 candles burned for 3 hours in a 40 m^3 room with realistic air flow conditions. Schwind and Hosseinpour (1994) analyzed candle materials and the combustion process, and created a worst-case scenario of 30 candles burned for 4 hours in a 50 m^3 room with approximately 0.7 L/min air flow. Fine et al. (1999) also performed a series of emission tests on the combustion of paraffin and beeswax candles burned in an air chamber with a volume of approximately 0.64 m^3 and an air flow rate of 100 L/min. Results of the studies are presented below and in Table 6.

Acetaldehyde

Acetaldehyde levels for 30 candles burned in an enclosed room for 3 hours were modeled at 0.834 $\mu g/m^3$ (Lau et al., 1997); this is above the EPA's 10^{-6} excess cancer risk level[6] of 0.5 $\mu g/m^3$, but below the EPA inhalation reference concentration (RfC)[7] of 9 $\mu g/m^3$.

Formaldehyde

Formaldehyde levels were measured at 0.190 $\mu g/m^3$ (Lau et al., 1997) and 17 $\mu g/m^3$ (Schwind and Hosseinpour, 1994). Again, these measurements were above the EPA's 10^{-6} excess cancer risk level of 0.08 $\mu g/m^3$, but below the OSHA PEL maximum of 921.1 $\mu g/m^3$. Formaldehyde levels for both studies were far below OSHA's STEL[8] maximum of 2,456.1 $\mu g/m^3$.

Acrolein

Maximum concentrations of acrolein were measured at 0.073 $\mu g/m^3$ (Lau et al., 1997) and <1 $\mu g/m^3$ (Schwind and Hosseinpour, 1994). These levels are above the RfC of 0.02 $\mu g/m^3$ and

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[6] 10^{-6} excess cancer risk level: This EPA comparison value is the air concentration known to produce an increased risk of 1 in 1,000,000 for cancer.
[7] RfC (Reference Concentration): This EPA health-based comparison value assumes that there is a threshold for certain toxic effects. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
[8] STEL (Short-Term Exposure Level): This OSHA standard was designed to limit maximum concentrations of exposure as averaged over any 15 minute period. This is an occupational standard, not designed for the protection of the general public, children, or sensitive populations.

below the PEL of 250 μg/m^3. A cigarette burned in a similar environment produces acrolein levels of 23 μg/m^3 (Lau et al., 1997).

Polychlorodibenzo-p-dioxins/Polychlorodibenzofurans (PCDD/PCDF)

Levels of PCDD/PCDF were measured at 0.038 pg I-TEQ/m^3 (Schwind and Hosseinpour, 1994). The TEQ is the toxic equivalency method used to evaluate dioxins. It represents the sum of the concentrations of the multiple dioxin congeners "adjusted" to account for the toxicity of each congener relative to the most toxic dioxin, 2,3,7,8-TCDD.

Polyaromatic Hydrocarbons (PAHs)

The amount of PAHs measured in candle emissions and soot differs between studies. Fine et al. (1999) found that no significant levels of PAHs were detected in the emissions from normal burning and smoldering candles. In contrast, Huynh et al. (1991) found that soot from wax-light church candles contained measurable concentrations of PAHs: the study measured 882 μg benzo[ghi]perylene per gram of candle soot and 163 μg benzo[a]pyrene per gram of candle soot. However, Huynh et al. did not measure PAH concentrations from candles in air. Wallace (2000) also concluded that a citronella candle was a source of PAHs in a study of real-time monitoring of PAHs in an occupied townhouse, but did not quantify the concentration or emission rate.

Concentrations of benzo[a]pyrene in air due to candle emissions can measure 0.002 μg/m^3 (Lau et al., 1997). This is below the PEL value of 200 μg/m^3. Naphthalene maximum concentration levels were measured at 0.04 μg/m^3 (Schwind and Hosseinpour, 1994), below the EPA RfC of 3 μg/m^3.

Alkanes, Wax Esters, Alkanoic and Alkenoic Acids, Alkenes

Fine et al. (1999) found that the majority of emissions from candles consisted of organic compounds including alkanes, wax esters, alkanoic and alkenoic acids, and alkenes. Some of the compounds found were thermally altered products of the unburned wax, while others were unaltered in the volatilization process. Concentrations of the organic compounds in air were not calculated.

Particulate Matter

The diameter of candle flame particles have been measured between 20 and 100 nm (Li and Hopke, 1993) and 100 and 800 nm depending on the mode of burning (Fine et al. 1999). Neither study calculated maximum concentrations of particles in air. Li and Hopke (1993) subjected candle flame particles to relative humidity comparable to that in the human respiratory tract, and found that candle flame particles grew in size. White candles had a 20% larger growth potential than scented candles.

Table 6: Indoor Air Impacts of Burning Candles

Contaminant	Study	Maximum Concentration	STEL	PEL	RfC	10^{-6} Excess Cancer Risk
Lead	Nriagu and Kim	0.02- 13.1 μg/m^3	NA	50 μg/m^3	NA	NA
	van Alphen	42.1 μg/m^3				
	Sobel et al.(2000a)	15.2 to 54.0 μg/m^3				
Zinc	Nriagu and Kim	1.2-124 μg/hour [a]	NA	NA	NA	NA
Tin	NA	NA	NA	NA	NA	NA
Acetaldehyde	Lau et al.	0.834 μg/m^3	NA	360,000 μg/m^3	9 μg/m^3	0.5 μg/m^3
Formaldehyde	Lau et al.	0.190 μg/m^3	2,456.1 μg/m^3	921.1 μg/m^3	NA	0.08 μg/m^3
	Schwind and Hosseinpour	17 μg/m^3				
Acrolein	Lau et al.	0.073 μg/m^3	NA	250 μg/m^3	0.02 μg/m^3	NA
	Schwind and Hosseinpour	<1 μg/m^3				
PCDD/PCDF	Schwind and Hosseinpour	0.038 pg I-TEQ/m^3	NA	NA	NA	NA
Benzo [*a*] pyrene	Lau et al.	0.002 μg/m^3	NA	200[1] μg/m^3	NA	NA
Naphthalene	Schwind and Hosseinpour	0.04 μg/m^3	NA	50,000 μg/m^3	3 μg/m^3	NA
Alkanes, Wax Esters, Alkanoic and Alkenoic Acids, Alkenes	NA	NA	NA	NA	NA	NA
Particulate	NA	NA	NA	NA	NA	NA

[a]This number represents an emission rate, not a concentration. A maximum concentration was not calculated for zinc.

Candle Soot

Black Soot Deposition (BSD) is also referred to as ghosting, carbon tracking, carbon tracing, and dirty house syndrome. Complaints of BSD have risen significantly since 1992 (Krause, 1999).

Black soot is the product of the incomplete combustion of carbon-containing fuels. Complete combustion would result in a blue flame, and would produce negligible amounts of soot and carbon monoxide. Until recently, the source for the black soot in homes was unknown. Through interviews and recent experiments, it is now believed that frequent candle burning is one of the sources of black soot. The amount of soot produced can vary greatly from candle to candle. One type of candle can produce as much as 100 times more soot than another type (Krause, 1999). For example, elemental carbon emission rates varied from <40 to 3,370 μg/g candle burned in a study of sooting behavior in candles (Fine et al., 1999). The type of soot may also vary; though primarily composed of elemental carbon, candle soot may include phthalates, lead, and volatiles such as benzene and toluene (Krause, 1999).

Scented candles are the major source of candle soot deposition. Most candle wax paraffins are saturated hydrocarbons that are solid at room temperature. Most fragrance oils are unsaturated hydrocarbons and are liquid at room temperature. The lower the carbon-to-hydrogen ratio, the less soot is produced by the flame. Therefore, waxes that have more fragrances in them produce more soot. In other words, candles labeled "super scented" and those that are soft to the touch are more likely to generate soot.

The situation in which a candle is burned can also impact its sooting potential. A small and stable flame has a lower emission rate than a larger flickering flame with visible black particle emissions (Vigil, 1998). A forced air flow around the flame can also cause sporadic sooting behavior (Fine et al., 1999). Thus, candles in glass containers produce more soot because the container causes unsteady air flow and disturbs the flame shape (Stephen et al., 2000). Candles that are extinguished by oxygen deprivation, or blowing out the candle, produce more soot than those extinguished by cutting off the tip of the wick. Cutting the wick eliminates the emissions produced by a smoldering candle (Stephen et al., 2000).

When soot builds up in air, it eventually deposits onto surfaces due to one of four factors. First, the particle may randomly collide with a surface. Second, soot particles can be circulated by passing through home air-conditioning filters. Third, soot can gain enough mass to become subject to gravity. Homes with BSD often have carpets stained from soot deposition (Vigil, 1998). Finally, the particles are attracted to electrically charged surfaces such as freezers, vertical plastic blinds, television sets, and computers (Krause, 1999).

When soot is airborne, it is subject to inhalation. The particles can potentially penetrate the deepest areas of the lungs, the lower respiratory tract and alveoli (Krause, 1999). ERG did not find research literature on the health effects of residential exposure to candle soot.

Conclusion

Candles with lead wicks have the potential to generate indoor airborne lead concentrations of health concern. It is also possible for consumers to unknowingly purchase candles containing lead wick cores and repeatedly expose themselves to harmful amounts of lead through regular candle-burning.

Lead wicks aside, consumers are also exposed to concentrations of organic chemicals in candle emissions. The European Candle Association (1997) and Schwind and Hosseinpour (1994) conclude that there is no health hazard associated with candle burning even when a worst-case scenario of 30 candles burning for 4 hours in a 50 m^3 room is assumed. However, burning several candles exceeded the EPA's 10^{-6} increased risk for cancer for acetaldehyde and formaldehyde, and exceeded the RfC for acrolein. Once again, the RfC and EPA's 10^{-6} increased cancer risk guidelines are not designed specifically for indoor air quality issues, so these conclusions are subject to interpretation.

Consumers may also not be aware that the regular burning of candles may result in BSD, causing damage to their homes. Sooting can be reduced by keeping candle wicks short, drafts to a minimum, and burning unscented candles.

Additional research may want to focus on gaps in the literature, such as emissions from scented and multi-colored candles, and maximum concentrations of organics in air produced by sooting candles.

4.B INCENSE

Several studies found associations between exposure to incense smoke and many illnesses, including cancer, asthma, and contact dermatitis. Incense burning was found to be a contributing factor in the occurrence of asthma for Quatar children (Dawod and Hussain, 1995), and coughing was found to be associated with incense exposure in a study of Taiwanese children (Yang et al., 1997). Burning incense produces volatile fragrances that, once airborne, can reach exposed skin, causing dermatitis (Roveri et al., 1998). An elevated risk for leukemia was found in children whose parents burned incense during pregnancy or while nursing (Lowengart et al., 1987). A study of childhood brain tumors showed elevated risk for children whose parents burned incense in the home (Preston-Martin et al., 1982).

From comparing mutagenic potencies of incense, formaldehyde, and acetaldehyde to *Salmonella typhimurium* T102, Chang et al. (1997) concluded that incense smoke contains highly active compounds with a higher mutagenic potency than formaldehyde. Sato et al. (1980) and Rasmussen (1987) have also found that incense smoke is mutagenic to *S. typhimurium* TA98, TA 100, and TA104. Incense Smoke Condensates (ISCs), the particles released during incense burning, were found to be mutagenic and/or genotoxic in the Ames test, the SOS chromotest, and the SCE/CHO assays. The genotoxicity of certain ISCs in mammalian cells was also found to be higher than particles produced from tobacco smoke condensates (TSCs) (Chen et al., 1990).

Interestingly, one study concluded that burning incense decreases the chances of developing lung cancer (Liu et al., 1993). However, this study was conducted in China, where societal factors may have influenced the results of the study. For example, people using incense may be more well off and therefore have healthier life styles in general (Liu et al., 1993). A few studies examined emissions of specific contaminants from incense smoke. These results are discussed below.

Carbon Monoxide

Carbon monoxide inhibits the blood's ability to carry oxygen to body tissues including vital organs such as the heart and brain. Symptoms of carbon monoxide exposure vary widely based on exposure level, duration, and the general health and age of an individual. Typical symptoms include headache, dizziness, and nausea. These 'flu like' symptoms often result in a misdiagnosis and can cause delayed or misdirected treatment. Contact with high levels of carbon monoxide can result in unconsciousness and death (EPA, 2000b).

Although Löfroth et al. (1991) found that burning incense produced sizeable amounts of carbon monoxide (220 mg/g incense burned), the authors concluded that it is not likely to exceed EPA regulatory standards unless the incense is burned in a very small room with very little ventilation. The standard used for a comparison value in the study was the EPA's outdoor ambient air quality standard of 10 mg/m^3. This is not necessarily the most appropriate comparison value, especially since mg/g incense burned, not maximum indoor air concentration, was reported.

Isoprene

Isoprene is a hydrocarbon created and emitted from plants and trees during respiration, and has also been detected in tobacco smoke and automobile exhaust. Isoprene does have genotoxic properties (EDF, 2000).

Interestingly, the predominant exposure to isoprene comes from its formation in the human body. An exhaled breath contains 1-3 mg/m^3 of isoprene. Löfroth et al. (1991) concluded that 1.1 mg isoprene/g incense burned would not result in adverse health effects. Again, maximum indoor air concentrations were not provided in this study.

Benzene

Löfroth et al. (1991) compared benzene emissions from the food preparation process, cigarette smoking, and burning incense. The study found that emissions of benzene resulting from burning an incense cone were 440 μg/g incense burned. Löfroth et al. concluded that this emission level could possibly cause an increase in indoor benzene concentrations above urban air background levels of 2-20 μg/m^3. A maximum indoor benzene concentration was not calculated in this study, so we cannot justifiably compare Löfroth's value to the EPA 10^{-6} excess cancer risk estimates, reported as a range of 0.13 to 45 μg/m^3 (EPA, 2000a).

Musk Xylene, Musk Ketone, and Musk Ambrette

Musk xylene (2,4,6-trinitro-1,3-dimethyl-5-tertiary butyl benzene), musk ketone (3,5-dinitro-2,6-dimethly-4-tertiary butyl acetophenone), and musk ambrette (2-methoxy-3,5 dinitro-4-methyl-tertiary butylbenzene) are contained in some types of Chinese incense (Roveri et al., 1998). They are known for making skin more sensitive to light and causing irritations. When incense is burned, airborne particles may dissolve in the upper layer of skin and allergic contact dermatitis may arise. However, toxicity and health data for these chemicals are not available.

Particulate Matter

Burning incense was found to generate large quantities of particulate matter (Mannix et al., 1996). Mannix et al. estimated the median diameter of particulates in aerosols to be between 0.24 and 0.40 μm, and hypothesize that particles could deposit in the respiratory tract. Mannix et al. did not perform a chemical characterization of compounds present in the particulate phase, but recommend that a human exposure scenario be done. Li and Hopke (1993) also found that incense smoke produced larger particles, in the range of 0.1 to 0.7 μm. Tung et al. (1999) found that PM_{10} concentrations in Hong Kong homes were 23% higher with smoking or incense burning– the mean indoor PM_{10} level for all homes was 78.8 $\mu g/m^3$, while mean PM_{10} for smoking or incense-burning homes was 96.6 $\mu g/m^3$. This is below the EPA's national ambient air quality 24-hour standard of 150 $\mu g/m^3$, but above the annual standard of 50 $\mu g/m^3$. Chao et al. (1998) found that burning incense in a home with poor ventilation could result in a peak concentration of total suspended particulates (TSPs) of 1,850 $\mu g/m^3$. In 1987, EPA began using PM_{10}, particles measuring 10 μm or less in diameter, rather than TSPs as the standard unit of measure. However, before that time, the standard for outdoor TSPs in the United States was 260 $\mu g/m^3$ for a 24-hour average and 75 $\mu g/m^3$ for an annual average. The concentration of particulates found in Chao et al. (1998) far exceeds 260 $\mu g/m^3$.

Polyaromatic Hydrocarbons (PAHs)

Reports of PAHs in incense soot have been contradictory. Chang et al. (1997) did not find PAHs in the vapor extract of incense smoke. However, Koo (1994) determined that PAH levels rose with incense burning in a study of Hong Kong residences. Incense soot was found to contain measurable concentrations of fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[def,p]chrysene, benzo[ghi]perylene, ideno[1,2,3,-cd]pyrene, anthanthrene, and coronene (Huynh et al., 1991). Though the study established that the maximum dust concentration corresponded with the burning of incense, maximum concentrations of PAHs from incense burning were not calculated.

Conclusion

Incense produces particulate matter that can deposit in the respiratory tract, and elevates airborne concentrations of carbon monoxide and benzene. Incense also contains trace amounts of chemicals suspected of causing skin irritation, and exposure to incense has been linked with several illnesses. Incense smoke should be considered a source of indoor pollutants in rooms in which incense is regularly burned (Cheng and Bechtold, 1995). However, the studies reviewed measured emissions for only a limited number of incense types and brands; with the large range of incense manufacturers and importers on the market, other incense types could differ in the parameters examined.

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