Potential exposure to metal fumes, particulates, and organic vapors during radiotherapy shielding block fabrication

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The shielding-block fabrication areas of three hospitals were surveyed to assess inhalation exposure to lead (Pb), cadmium (Cd), bismuth (Bi), and tin (Sn) fumes, as well as styrene and methyl chloride vapors. Area and personal breathing zone samples were collected for various steps in the block fabrication process. Only 3 of 16 air samples for metals resulted in detectable levels of Pb and/or Cd. The levels were well below the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits, excluding a sample which contained a visible metal fragment. Bi and Sn were not detected in any samples. Methyl chloride and styrene vapors were not detected in any air samples during foam cutting procedures. Total particulates (TP) were measurable in 11 of 17 air samples (ranging from 0.01 to 2.1 mg/m^3). TP values were below the OSHA federal standard for nuisance particulates, which is 15 mg/m^3. The data suggest that the materials and procedures sampled do not present an inhalation hazard to employees who construct shielding blocks. Precautions should, however, be exercised to prevent exposure under extreme procedural conditions such as soldering or overheating of alloy, and by other means such as ingestion. Care should also be taken during cleanup or housekeeping to prevent re-entrainment into the work atmosphere of mechanically generated metal particles or materials condensed within melting pots (which may be high in metal content).

INTRODUCTION

Metal shielding blocks are used between radiation sources and patients to "shadow" areas not requiring irradiation. Shields cast from molten lead (melting point 327 °C) are expensive to make and may expose personnel to high temperatures as well as toxic lead fumes. Due to easier handling and lower melting points, the use of lead alloys rather than pure lead has rapidly become the most popular method for construction of radiotherapy shielding blocks. The transition from the use of pure lead to lead alloys may have reduced concerns over toxic exposure to lead fumes, but new potential hazards may have been introduced. Although the composition of available alloys varies somewhat, several of them contain not only lead but cadmium, bismuth, and tin.

The Occupational Safety and Health Administration (OSHA) has established the following levels of exposure (based on an 8-h workday) for Sn, Cd, and Pb, known as Permissible Exposure Limits (PEL)[1]:

Sn 2000 μg/m^3
Cd 100 μg/m^3.
Pb 50 μg/m^3

A PEL has not been established for exposure to Bi. Information concerning the health effects associated with exposure to these metals may be found elsewhere.[2,3]

Exposure to alloy metals may occur by inhalation of metal fumes from open melting pots or during soldering and pouring. Inhalation may also be a route of exposure for particulates generated from pouring molten metals or during filing and soldering. Ingestion is also a potential route of entry if poor handling procedures or work practices are exercised (smoking, eating, or drinking in the block making area).

Potentially hazardous inhalation exposures to organic vapors may occur during polystyrene foam cutting in preparation of block molds. At least one major brand of plastic foam uses methyl chloride (as one of the expanding agents[4]) and styrene. Both may be released during hot-wire cutting to form the mold. Methyl chloride as well as styrene exposure should not exceed 100 ppm average for an 8-h work period. The acceptable ceiling limit for both of these chemicals is 200 ppm.

McCullough and Senjem[5] had previously measured airborne concentrations of the alloy metals over melting pots when operating at elevated temperatures. Their analysis revealed nondetectable results for 11 of 20 samples, and concentrations in air well below the OSHA PEL for the samples containing measurable amounts of metal elements. The investigation by McCullough and Senjem did not, however, include monitoring personal exposure levels, nor did it address the issue of potential exposure to the vapors released during foam cutting.

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This study investigates the actual breathing zone exposure levels of personnel during the block making process. It includes the sampling of airborne metal fumes which may be produced during melting, pouring, and molding of blocks, and sampling for methyl chloride and styrene, which may be released during the formation of polystyrene foam molds.

MATERIALS AND METHODS

Area and personal breathing zone samples were collected for various steps of the block making process, and analyzed as prescribed in the National Institute of Occupational Safety and Health (NIOSH) Manual of Analytical Methods.[6]

Sampling was conducted in the radiation therapy department of three hospitals, identified here as sites A, B, and C. The block production facilities varied somewhat for each of these locations but each used the cerrobend Ostalloy alloy (13.3% Sn, 50.0% Bi, 26.7% Pb, 10.0% Cd), which has a melting point of 70 °C.

A few modifications had been made in the block making process at site A, such as the addition of a water-cooled table to reduce hardening time and the use of a dowel rod during pouring to reduce the formation of bubbles and to create smoother block surfaces. Block production at site A was estimated to be 15 blocks per day.

Unlike other sites, the melting pot for site B was in operation 24 h per day. Until the time of this study, water had been placed on the surface of the alloy in the melting pot, theoretically to reduce fume production. In order to obtain a worst-case exposure situation, however, the study was conducted without the use of water. Block production at site B was estimated to be four blocks per day.

The block making room for site C was exceptionally well ventilated, since it was originally designed to house a computer which required continual cooling. As with site B, water was removed from the surface of the alloy in the melting pot during the study. A fine black powder, collected from the inside of the melting pot, had accumulated while water was being used. Block production at site C was estimated to be four blocks per week.

Sixteen metal samples were collected for various parts of the block production process. Worst-case exposures to the metals contained in the alloy were estimated by 8-h samples taken directly above the alloy melting pots (approximately 30 cm). Stationary samples, taken only during the pouring of the melted alloy into the molds, represent peak exposures while personal samples represent the actual time-weighted averaged exposure during an 8-h workday.

A bulk sample of a fine black powder, contained on the side walls and inside of the lid of one melting pot, was analyzed for its composition to determine its source and to provide information about how the composition of the alloy changes upon vaporization.

The sampling strategy for total particulate sampling is similar to that for the metals. Worst-case exposures were estimated by stationary breathing zone samples. Samples taken during the pouring of molds as well as during filing and soldering of the finished block represent peak exposures, while the time-weighted average exposure is represented by 8-h personal samples.

TABLE I. Metal composition of powder sample from side wall and lid of melting pot.

Metal	Sample % (by mass)	Original alloy % (by mass)
Pb	10.8	26.7
Cd	16.6	10.0
Bi	22.9	50.0
Sn	11.2	13.3
	61.5	100.0

Stationary breathing zone samples were collected during hot-wire cutting of foam molds to estimate peak exposures to styrene and methyl chloride. Background samples for metals and total particulates (TP) were also collected in rooms where neither mold cutting nor alloy cutting occurred.

RESULTS

Three of 16 air samples for metals resulted in detectable levels of Pb and/or Cd. A personal sample contained 2.06 $\mu g/m^3$ Pb and 1.49 $\mu g/m^3$ Cd. A sample taken over soldering (for a duration of only 27 min) showed a Cd level of 16.8 $\mu g/m^3$. A third sample taken over a melting pot showed a Pb level of 46.9 $\mu g/m^3$ and a Cd level of 18.7 $\mu g/m^3$ (this sample contained a visible metal fragment).

Blood tests had been conducted previously at site A for the two full-time blockmakers to determine blood levels of Pb and Cd. Both employees had blood lead levels of less than 10 $\mu g/100$ ml and blood cadmium levels of less than 0.1 $\mu g/100$ ml.

Table I indicates the metal composition found by an analysis of the fine black powder collected from the side wall and lid of one melting pot. Methyl chloride and styrene were not detected in any air sample. Total particulates were measurable in 11 of 17 air samples ranging from 0.01 to 2.1 mg/m^3.

DISCUSSION

The metal levels detected in 3 of 16 air samples were well below those of the OSHA PEL, excluding the sample which contained a visible metal fragment. This fragment most likely resulted from the splashing of melting alloy and does not necessarily represent the true inhalation exposure. A visible particle of this size (much greater than 10 μm) would either settle before it could be inhaled or would be trapped in the nasopharynx region of the upper respiratory system, and would not reach the lungs. (This would also hold true for particles produced by filing.)

Each of the other two samples containing measurable amounts of metals were taken during the soldering of already hardened alloy. Soldering irons melt the alloy at a much higher temperature than do the melting pots during normal operation. These higher temperatures are more conducive to the formation of metal fumes than other procedures sampled, but soldering is usually of much shorter duration.

The blood analyses for the two blockmakers at site A indicate normal blood levels for both metals. Normal blood lead levels range from 0 to 35 $\mu g/100$ ml of blood.[7] The tentative biologic threshold limit value for Cd in blood is 1 $\mu g/100$ ml.[2]

The powder sample collected from the side wall and lid of one melting pot consisted of a high percentage of what is probably metal fume, produced by all metals in the alloy. Therefore, this powder should be treated with caution and cleaned or removed carefully to prevent excessive airborne concentrations of the particulates. Other constituents contributing to the formation of this fine powder might be fragments of polystyrene foam or even the mold release fluid, both of which may be present on old blocks which are remelted. However, the analysis obviously shows an abundance of metals. It is not clear why such heavy deposits occurred in the melting pot at this site. This type of accumulation was very low or absent at sites A and B. These deposits are unrelated to detectable levels of metals in air.

Nondetectable results were reported in all methyl chloride and styrene samples. This might be attributed to the short duration of the foam cutting procedure.

Detectable levels of total particulates were measured for all but five samples. The values obtained for these samples may be compared to the OSHA PEL for "nuisance particulates" which is set at 15 mg/m^3.[1]

As indicated, all samples collected fall below the listed OSHA limits. These limits refer only to airborne concentrations of the specific substances listed and do not consider exposure by other means such as ingestion.

CONTROL MEASURES

The major potential hazards to block making personnel have been summarized in other studies[8]: (1) bruises to hands or feet from dropped blocks, (2) burns from handling molten alloy heated above 70 °C, (3) inhalation of metallic dust particles and fumes, (4) ingestion of metal alloy, and (5) skin absorption of metal alloy. The potential lifting hazard, posed by placing very heavy blocks into position on the treatment machine, might also be added to this list. The NIOSH Work Practice Guide for Manual Lifting summarizes research and provides recommendations to control potential hazards associated with lifting.[9]

Control measures can be implemented to prevent potential hazards of block making. These measures might include the use of exhaust ventilation or a fume hood for operations involving melting, filing, pouring, and soldering. Dust and debris from filing and plastic cutting should be removed frequently to avoid accumulation. Protective clothing such as aprons or thermal work gloves may be used to avoid contact with molten alloy. Eating, drinking, and smoking should be prohibited in the block making area. Blood Pb tests do not appear to be warranted but they are feasible and would be required if exposure were sufficiently high. Not all control procedures may be required or practical for all sites. It is important, however, that employees be trained in the proper techniques for block fabrication and that they be made aware of the potential hazards associated with each alloy.

SUMMARY AND CONCLUSIONS

This study indicates that inhalation exposure to metals and organic vapors during the construction of radiotherapy block shields is minimal. Commonly used metal alloys are apparently melted at sufficiently low temperatures to minimize the production of potentially harmful metal fumes. Results show that exposures to methyl chloride and styrene are nondetectable during foam cutting. Precautions and control measures will help to reduce exposures by routes other than inhalation.

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