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Relationship Between Air Sampling Data from
Glove Box Work Areas and
Inhalation Risk to the Worker

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RELATIONSHIP BETWEEN AIR SAMPLING DATA FROM GLOVE BOX WORK
AREAS AND INHALATION RISK TO THE WORKER

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ABSTRACT

A mockup of a plutonium work area was equipped to simulate and monitor aerosol leaks from a glove box into the worker's environment. Dioctyl phthalate was the tracer aerosol used, and aerosol concentration throughout the work area was monitored under several different ventilating conditions. Aerosol concentration in the worker's breathing zone was up to 250 times greater than the concentrations which might be indicated by typical fixed room-air samplers located adjacent to the glove box. The effect on the magnitude and pattern of aerosol dispersal was evaluated in light of ventilation rate and direction of the ventilating air flow relative to the leak.

I. INTRODUCTION

Air sampling is frequently used to determine the concentration of airborne contaminants present in a work environment, and provides one criterion for assessing risk to personnel. Ideally, air samples should be taken at a worker's breathing zone, with the sampling probe located adjacent to his nose, but this is generally impractical. A personal sampler could be worn close to the breathing zone but the worker would have to carry a battery pack, vacuum pump assembly, and sampling probe, thereby restricting his movements and impairing his efficiency. Personal samplers generally measure aerosol concentrations that are 2 to 10 times (sometimes over 30 times) higher than those measured by fixed area samplers.^{1,2} Even so, personal samplers may give too low an indication of

inhalation hazards because workers tend to wear them away from the actual breathing zone.

When plutonium particle releases were measured³ in glove box work areas using paired, adjacent area samplers, only one-third of the paired measurements agreed within $\pm 50\%$. The difference in alpha activity was caused by the relatively small number of airborne plutonium particles present. However, the release of even a few plutonium particles is of concern because ~ 63 1- μ m particles constitute the maximum permissible daily dose of $^{239}\text{PuO}_2$, and if $^{238}\text{PuO}_2$ is involved, just one 1- μ m particle exceeds the permissible daily dose. Room samplers may not indicate the potential hazard because of the limited number of contaminant particles in the air

and the fact that the high specific activity is released from a point source. In addition, air sampling data may vary greatly^{4,5,6,7} due to the failure to achieve representative sampling of the aerosol cloud, random errors in determining the amount of material collected by the sampler, operational errors in flow rates, and handling losses occurring prior to analysis.

To quantitate the relationship between aerosol concentrations at typical sampler locations and at worker breathing zone areas, an experimental air sampling program was initiated. A simplified glove box work area was constructed to permit simulation of an industrial-type accidental aerosol release into a worker's environment. Aerosol concentration variations were monitored as a function of space, time, and ventilating conditions. Potential breathing zone and air sampling air concentrations were compared.

II. EXPERIMENTAL PROCEDURES

A. Experimental Setup

The work area for this study was a 20 x 20 x 8-ft room containing a single glove box. An orthogonal coordinate axis system, relative to the leak source, was established to define air sampling locations. The coordinate system (Fig. 1) consisted of an L axis parallel to the floor, perpendicular to the front of the glove box, and originating at the leak source; an horizontal axis (H) designated as plus (right) or minus (left) from the L axis; and a vertical (V) axis defining distance above (plus) or below (minus) the leak source. A floor-to-ceiling pole could be located anywhere in the room and the sampling probe positioned vertically along this pole, with the leak source as the origin of the coordinate axis system. A sampling point that was 3 ft in front of, 4 ft to the left of, and 1 ft above the leak source would have the coordinates 3, -4, 1.

Fig. 1. Coordinate system used in room for positioning sample probe.

The glove box was placed on a large table which could be moved to change the orientation of the aerosol leak flow direction. One glove port was covered with an aluminum plate with a 1/8-in. hole drilled in the center to allow the aerosol to escape into the room. The other port held a glove which permitted the recharging and positioning of the aerosol generator. The leak orifice was so situated that concentration data could be collected from an area up to 2 ft above, 3 ft below, 7 ft to either side, and 10 ft in front of the leak source.

To produce a sub-micron tracer aerosol, an air-operated dioctyl-phthalate (DOP) aerosol generator with a single jet impactor⁸ was placed inside the glove box. Aerosol-generator air pressure was monitored continuously to keep aerosol size characteristics constant because the response of the light-scattering photometer used as the aerosol concentration monitoring device varies with aerosol size.

Aerosol dispersal patterns were defined under the following simple ventilating conditions: 6, 9, and 12 room air changes per hour (ac/h) for each of three different air flow directions (0°, 90°, 180°)

relative to the aerosol leak flow direction. For 0° orientation, room air enters from behind the glove box and flows in the same direction as the aerosol leak; for 90° orientation, room air enters from one side of the room perpendicular to the leak flow direction; and for 180° orientation, room air enters the room from the wall opposite the glove box and flows in the opposite direction from the leak flow.

The ventilating air entered through an 8-in.-deep inlet plenum covering the entire width of the experimental room. From this plenum the entering air was uniformly distributed across the entire wall through 1/8-in.-diameter holes spaced 1 in. apart. The outlet plenum, on the opposite wall, was identically constructed.

Room aerosol concentration was measured with a Los Alamos Scientific Laboratory light-scattering photometer, model 69B.⁹ Approximately 640 air concentration measurements were taken throughout the room over a period of several days to define fully the aerosol dispersal patterns for each ventilating condition. Because of this relatively long time span, it was imperative to eliminate the effect of time on aerosol concentration in the room. In addition, the following parameters were kept constant: (1) aerosol-generator air pressure; (2) glove box internal pressure; (3) room air pressure; (4) ventilating air flow distribution; (5) sampling flow rate; and (6) aerosol particle size characteristics.

Most of the conditions in this experimental study were similar to a simple actual work situation, but some differences did exist. For the experiment, a steady-stream leak was used, whereas an actual work situation would probably produce a short-lived pulse or puff of aerosol. Also, there was nothing in front of the glove box to simulate a worker. Another difference between experimental and actual conditions was the initial velocity of the aerosol

stream. In the experimental situation, the aerosol stream was under a constant pressure (+ 1-in. w.g. in the glove box) which imparted a certain initial velocity to the aerosol leaving the glove box. In an actual work situation, the velocity of the aerosol varies with operational circumstances at the time of release.

B. Sampling and Analytical Procedures

The light-scattering photometer was operated at a sampling flow rate of 10 liters/min. Individual room air concentration measurements were taken continuously for 2 to 3 min, recorded on a strip chart, and an average concentration calculated for that sampling location. One minute was allowed between readings for repositioning the sampling probe and minimizing air turbulence resulting from operator movements. Concentration data were plotted as iso-concentration curves within horizontal planes at the leak level, 1 and 2 ft above the leak level, and 1, and sometimes 2 ft below the leak level for each test condition. These data show aerosol dispersal patterns as a function of the different ventilating air flow rates, and varying direction of the ventilating air flow relative to the aerosol leak flow direction. Extrapolation provides an approximation of the error associated with estimating worker exposure from air sampling data.

Several locations in the room were sampled at 60-sec intervals to see that aerosol concentration remained constant throughout each experimental day. Data thus collected at the leak level for five sets of conditions were analyzed for the ratio of aerosol concentration at time zero (C_0) to the concentration at a later time (C_t). Three-way analysis of variance statistical procedures^{10,11} was applied to these data to permit a direct comparison of data collected under different ventilating conditions and/or over long time periods. The three-way analysis of variance showed that, at the 0.05 confidence level, time

had no significant effect on aerosol concentrations.

Andersen impactors^{12,13} were used for characterization of the aerosol size distribution and for evaluation of any changes in aerosol size due to gravitational settling or aerosol agglomeration. Particle size characteristics measured by the Andersen impactor ranged from a mass median aerodynamic diameter (mmad) of 0.640 to 0.86 μm , with a geometric standard deviation (σ_g) of 1.48 to 1.49. Of approximately 30 Andersen impactor samples collected, the average mmad was 0.75 μm , with an average σ_g of 1.49. This compared favorably with the data published for the same aerosol generator under similar operating conditions.⁸ The possibility of preferential settling of large particles was also evaluated by Andersen impactor sampling. In several cases, samples were collected at a fixed distance from the leak, and at vertical positions $V = +2$, $V = 0$, and $V = -2$. The median aerodynamic diameter for these samples failed to show preferential settling of larger particles. Analysis of variance tests applied to these data showed no statistically significant change in mmad, at the 0.5 confidence level, due to varying sampling location or day-to-day variations in aerosol generation. Elimination of this preferential-settling variable is critical because photometer response is particle-size dependent; that is, the intensity of light scattered and measured by the photomultiplier tube depends on the size of the aerosol particles. Because the particle-size characteristics were well controlled, the results were reproducible and comparable throughout the several months of the experimental phase.

III. RESULTS

Variations in aerosol concentration throughout the simulated work area under several conditions of ventilation are summarized in Figs. 2-19. Of 44 concentration

graphs that represent all the experimental data collected, only 18 are presented here, but all data and conclusions are consistent with those detailed in this paper.

Under all conditions tested, concentration levels changed rapidly with small positional changes close to the glove box. Aerosol concentration directly in front of the leak orifice at the leak level (along the L axis) decreases from 100 to 5% within 3 ft. An even more drastic change occurs when the position changes horizontally or vertically.

Figures 2, 3, and 4 show this variation in a horizontal plane at the leak level for 12, 9, and 6 ac/h, respectively, for the 0° orientation. Lateral dispersal (along or parallel to the H axis) results in a concentration decrease from 100% at the leak source, to less than 0.1% within 2 or 3 in. closer to the glove box. Farther out (along the L axis), air concentration decreases more slowly to 0.1%. A comparison of these three graphs shows the effect

Fig. 2. Iso-concentration curves within horizontal plane at leak level, 12 room air changes per hour 0° angle air direction.

Fig. 3. Iso-concentration curves within horizontal plane at leak level, 9 room air changes per hour, 0° angle air direction.

of the room air flow rate. At 12 ac/h (Fig. 2) the 0.11 to 0.50% iso-concentration area is confined to a space within 2 to 4 ft on either side of the leak source. At 9 ac/h (Fig. 3) this same zone extends to 6 ft on one side and more than 7 ft on the other side of the leak, and at 6 ac/h (Fig. 4) this lateral dispersal is even greater. Work areas directly in front of and close to the leak source generally show aerosol concentrations in excess of 10%.

Aerosol concentration in the horizontal plane 1 ft above the leak level follows a different pattern, with the minimum aerosol concentration close to the glove box and higher concentrations farther out. The closest single approximation to the worker's breathing zone is probably 1 ft above and close to the leak. For 0° orientation, aerosol concentration in this area ranges from 0.11% at the highest room air flow

Fig. 4. Iso-concentration curves within horizontal plane at leak level, 6 room air changes per hour, 0° angle air direction.

rate (12 ac/h, Fig. 5) to 1.0% at the lowest (6 ac/h, Fig. 6).

Figures 7 and 8 show the variation in aerosol concentration within a horizontal plane 2 ft above the leak level--a convenient location for area air samplers in glove box work areas. Data were taken at this level for all conditions studied, but only one measurement showed concentration levels as high as 0.60% near the glove box (6 ac/h, Fig. 7). In all other cases the air concentration at this level close to the glove box remained below 0.5% (9 ac/h, Fig. 8). These air concentrations measured by typical fixed air samples, are well below those previously noted in a worker's breathing zone at leak level or 1 ft above.

With a 90° orientation of ventilating air relative to the leak flow direction, aerosol concentrations also changed rapidly close to the leak source and less rapidly farther out. Figures 9, 10, and 11 show

Fig. 5. Iso-concentration curves within horizontal plane 1 ft above leak level, 12 room air changes per hour, 0° angle air direction.

Fig. 7. Iso-concentration curves within horizontal plane 2 ft above leak level, 6 room air changes per hour, 0° angle air direction.

Fig. 6. Iso-concentration curves within horizontal plane 1 ft above leak level, 6 room air changes per hour, 0° angle air direction.

Fig. 8. Iso-concentration curves through horizontal plane 2 ft above leak level, 9 room air changes per hour, 0° angle air direction.

this rapid change at the leak level. Along the L axis, aerosol concentration varies from 100% at the leak source to 4% at a 3-ft distance, similar to the 0° orientation (Figs. 2-4). The effects of room air flow rate and air direction are also evident. Lateral dispersal is very uneven, with the aerosol concentration being close to background along the positive side of the H axis where ventilating air enters the room, and up to 2% on the side along the negative H axis away from the ventilating air. At the higher air change rates the 90° air direction, aerosol dispersal is erratic at distances over 4 ft from the leak source; that is, the iso-concentration zones do not follow a smooth transition pattern from high to low concentrations with increasing distance. This effect is not evident at the lower air flow rates (Fig. 11). Experimental data (Figs. 12-14) indicate dispersal at 1 ft and 2 ft above

Fig. 10. Iso-concentration curves within horizontal plane at leak level, 9 room air changes per hour, 90° angle air direction.

Fig. 9. Iso-concentration curves within horizontal plane at leak level, 12 room air changes per hour, 90° angle air direction.

Fig. 11. Iso-concentration curves within horizontal plane at leak level, 6 room air changes per hour, 90° angle air direction.

the leak levels is greater for 90° than for 0° at distances more than 3 ft from the leak source. Air concentration levels at these distances, and 1 ft above the leak, (12 ac/h, Fig. 12 and 6 ac/h Fig. 13) range from 0.04 to 4.0%. Typical breathing zone aerosol concentrations range from 0.10% to greater than 10.0%, again depending on the exact location of the worker's breathing zone. Aerosol concentrations at 2 ft above the leak level and close to the glove box ranged from 0.10 to 0.50%. This is the area where fixed room air samplers are frequently located to estimate worker exposure. Farther out within this same level concentrations ranged from 0.11% to 2.0% (Fig. 14). Aerosol concentrations at 1 ft below the leak level under all conditions studied ranged from 0.01% to 1.0% (Fig. 15).

When ventilating air enters the room in a direction opposite to the leak flow (180° orientation), aerosol dispersal follows the same general patterns as in the two other

Fig. 12. Iso-concentration curves through horizontal plane 1 ft above leak level, 12 room air changes per hour, 90° angle air direction.

Fig. 13. Iso-concentration curves through horizontal plane 1 ft above leak level, 6 room air changes per hour, 90° angle air direction.

Fig. 14. Iso-concentration curves through horizontal plane 2 ft above leak level, 12 room air changes per hour, 90° angle air direction.

Fig. 15. Iso-concentration curves through horizontal plane 1 ft below leak level, 12 room air changes per hour, 90° angle air direction.

Fig. 16. Iso-concentration curves within horizontal plane at leak level, 12 room air changes per hour, 180° angle air direction.

orientations. At 180° orientation the higher room air flow rates (12 ac/h, Fig. 16) tend to keep the iso-concentration zones confined to a narrower space than do the lower room air flow rates (6 ac/h, Fig. 17). However, all iso-concentration areas are more widely dispersed at 180° than at 0° or 90°. Lateral dispersal was such that at 4-ft longitudinal distance the aerosol concentration ranged from 4.0% at the center to 0.5% at either wall (± 7 ft) under high room air flow rate (Fig. 16). At the lowest air flow rate (Fig. 17), the range was from about 4.5% at the center to 2.0% at one wall and 1.0% at the other. Aerosol dispersal at levels other than the leak level (12 ac/h, Fig. 18 and 6 ac/h, Fig. 19) was also much greater at 180° than at the other orientations, and greater at 6 ac/h than at 12 ac/h with this orientation. Typical breathing zone aerosol concentrations close to and 1 ft above the leak source at the 180° orientation generally ranged from 0.1 to 1.0% but did occasionally exceed 10.0%. Extensive data

were also obtained at 3 and 6 in. above, below, and on either side of the leak source. These data showed aerosol concentrations up to 4.0% at levels immediately above the leak level. The concentrations (up to 4.0%) occurred at the same time and conditions when concentrations at typical fixed air sampler locations (close to the glove box and 2 ft above the leak) ranged from 0.04 to 0.6%.

IV. DISCUSSION

Under all conditions of ventilation, aerosol concentrations ranging up to 4.0% occurred within the probable breathing zones (leak level to 1 ft above) at distances 4 to 10 ft from the leak source. These concentrations present an additional unevaluated potential inhalation hazard to personnel working at nearby glove boxes. At the same time, close to and 2 ft above

Fig. 17. Iso-concentration curves within horizontal plane at leak level, 6 room air changes per hour, 180° angle air direction.

Fig. 19. Iso-concentration curves through horizontal plane 1 ft above leak level, 6 room air changes per hour, 180° angle air direction.

Fig. 18. Iso-concentration curves through horizontal plane 1 ft above leak level, 12 room air changes per hour, 180° angle air direction.

the leak, where a fixed room air sampler may be located, aerosol concentrations ranged from 0.04 to 0.6%, whereas breathing zone concentrations immediately in front of the leaking glove box ranged from 0.11 to greater than 10.0%. This represents a potential maximum ratio of breathing zone aerosol concentration to fixed room air sampler concentration of 250. Common practice requires that air sampling data showing more than 0.067 disintegrations per second per cubic meter (dis/sec/m^3) be investigated, the source determined, and the problem remedied. It is conceivable that up to 16.7 dis/sec/m^3 could be present at the breathing zone before the area air sampler indicated $0.067 \text{ dis/sec/m}^3$.

It appears that the difference between breathing zone and fixed room sampler aerosol concentrations may be greater than indicated by these data. The general direction of the ventilating air flow in many work situations is from ceiling to floor at

the rate of 6 to 30 ac/h. The lower air change rates allow wider dispersal of the aerosol, thereby involving more people in the potential inhalation risk. The high air change rates permit less dispersal, introducing the potential for local hot spots which may not be noted by room air samplers. The ceiling-to-floor direction of the ventilating air may tend to direct the aerosol away from the sampler located close to and above the glove box. Furthermore, with a worker standing in front of the box, possibly preventing the aerosol from getting too far from the leak, the breathing zone levels may be higher than the experimental data show, although this could also increase the aerosol concentration at the air sampler.

These differences between potential breathing zone and air sampling air concentrations indicate the need for reconsideration of the following: (1) positioning of fixed area air samplers in existing plutonium facilities; (2) positioning of fixed area air samplers relative to ventilating air flow direction in proposed facilities; and (3) ventilation rate for proposed facilities. Ideally, breathing zone samples should be taken in addition to samples from fixed area air samplers located where ventilation conditions optimize the sampling efficiency. Personal samplers should be used whenever possible and particularly whenever breathing zone samples are impractical.

SUMMARY

With DOP as the tracer aerosol, aerosol concentration measurements were made in the vicinity of a glove box leak to quantitate the relationship between typical air sampler aerosol concentrations and breathing zone samples. General ventilating conditions were varied as to number of room air changes per hour and air direction relative to the leak flow direction.

Results show that under all ventilating conditions the highest aerosol concentrations (0.11 to 10.0%) were close to and in front of the leak source. Concentrations at typical air sampling positions ranged from 0.04 to 0.6%. Aerosol concentrations in excess of permissible concentration could be present at times when air samples indicated safe levels. This points up a potentially serious problem and the need for additional experiments under more realistic conditions.

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