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VENTILATING-AIR CHANGE RATE VERSUS PARTICULATE CONTAMINANT SPREAD

G. Langer

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VENTILATING-AIR CHANGE RATE VERSUS PARTICULATE CONTAMINANT SPREAD

G. Langer

ABSTRACT

This study provides information on the spread of particulate contamination from glovebox leaks in plutonium manufacturing facilities, with emphasis on the effect of ventilating-air change rate on contaminant spread. A new, very sensitive aerosol tracer technique was developed to simulate plutonium aerosol leaks and its dispersion in a room. The tracer, a submicron aerosol of phloroglucinol, does not interfere with work activity and is detected by its ability to form ice crystals in a supercooled cloud. This technique was applied in Buildings 371 and 707 plutonium production areas. The tracer spread throughout the rooms in a few minutes and reached its equilibrium concentration in 10 to 25 min. Also, to clear the room of all tracer took about the same time. In one room, tracer concentration decreased proportionally to the air change rate, while in the second one, air change rate had no effect. This points out the need for air velocity data. Also, future work must include simultaneous particle concentration measurements at several points.

INTRODUCTION

The objective of this study was to determine the effect of ventilation rate on the dispersion, concentration and clearance of contaminant aerosols from leakage incidents involving gloveboxes in plutonium manufacturing areas. Of major interest was data on the distance contaminants spread in a room depending on air change rate. Previous work at Rocky Flats Plant (RFP) indicated that higher air change rates confined the contaminants to a smaller volume of the room.¹ Therefore, efforts to reduce the large RFP energy cost by running the ventilating fans slower must be tempered by consideration for worker safety. However, if contaminants are mixed fairly uniformly in a room, a higher air change rate will

dilute the contaminants and increase the time before a Selective Alpha Air Monitor (SAAM) would alarm.

This report deals with the application of an aerosol tracer to study these questions. The use of a smoke tracer to directly visualize flow patterns in a room was the subject of a separate study.²

Three tests were carried out with the aerosol tracer: (1) Steady state aerosol tracer releases from one location were made in Building 371, Room 3206, to simulate a glovebox leak. The tracer was tracked throughout the room at different heights and at different air change rates. (2) In Building 707, Module D, tests were conducted similar to those under Test 1. But this time the tracer source was moved around the room to simulate glovebox leaks at different locations, instead of tracking one leak throughout the room. Tests at different air change rates were carried out with the detector at the same SAAM, while releasing tracer from different points in nearby glovebox bays. The object was to determine the response time of the SAAM versus air change rate. (3) A study was made to determine if the present 7-ft high airhead location on gloveboxes provides maximum response to aerosols that reach the breathing zone from a leak.

EXPERIMENTAL PROCEDURES

The tracer aerosol was generated with an atomizer of the design shown in Figure 1. The main feature of the atomizer is its scrubbing action. The drops formed at the nozzle pass through the liquid bubbling up the inner cylinder that surrounds the nozzle. This scrubbing action removes any large drops. The escaping fine droplets evaporate by the time they leave the exhaust tube. About 5 lb air pressure is required to run the atomizer. A water solution of phloroglucinol is used to generate the tracer particles upon evaporation of the water.

FIGURE 1. Salt Solution Atomizer

Phloroglucinol (trihydroxybenzene) is a weakly acidic organic compound, which has the rare property of converting supercooled water drops to ice. The importance of this property will become apparent later.

The atomizer was covered to avoid exposure to direct light, which slowly decomposes the chemical. One solution charge is good for several months. A 3- ℓ pm air flow produces an output over 1×10^8 particles/min. Most of the particles are smaller than $0.1 \mu\text{m}$ and not visible. Phloroglucinol presents no health hazard.³ The mass of the particles released is negligible; i.e., $<1 \mu\text{g/hr}$. The particles decompose in a day. A long piece of tubing attached to the atomizer outlet makes it possible to release the tracer at any desired

location, without moving the atomizer and compressed air supply.

The tracer particles are detected in a cloud chamber held at -18°C . The device is shown in Figure 2 and weighs 130 lb. The 10- ℓ pm sample stream is humidified and then mixed with 3 ℓ pm of a fine ($<0.1\text{-}\mu\text{m}$) salt aerosol. Upon cooling of the air, moisture condenses on the salt particles. The resulting $\leq 10\text{-}\mu\text{m}$ diameter droplets, upon further cooling to -18°C , become supercooled. Since the phloroglucinol crystalline structure is similar to ice, any phloroglucinol particles in the cloud behave like ice crystals. As a consequence, water vapor that has condensed on the phloroglucinol particles turns into ice below -10°C . The same applies if water drops collide with

FIGURE 2. Aerosol Tracer Detection System

phloroglucinol crystals. These ice crystal embryos grow in a few seconds to over $20\text{ }\mu\text{m}$ at the expense of nearby water droplets, because water vapor pressure is higher than that of ice. The large ice crystals set off a shock wave when they flow through the 1.5-mm glass capillary at the chamber exit.⁴ This audible acoustic signal is easily recorded by a microphone. The millions of water drops passing through the capillary do not trigger it. The maximum counting rate is about 10,000/min. The lower detection limit depends on the background aerosol particles. With filtered building air, the background count is less than 0.1/min and some of that count is due to electronic noise.

Up to 50 ft of sampling hose was attached to the detector to determine the tracer concentration at various points. A tripod was used to locate the intake at various levels above the floor. The recording electronics plots the count versus time and separately integrates the total count over a selected time interval. The detection system needs no attention after it is operational.

To quantify the tracer dispersion, the source concentration (particles/l) or the source strength (particles/min) must be known. To this end, 50-cc syringe grab samples were collected at the atomizer outlet. This 50-cc sample was then diluted, resulting in a dilution factor of 125, by

expelling 40 cc of the sample and replacing it with clean air. This was done 3 times. Then the sample was injected into the counter that was supplied with clean air from a filter. This procedure was also used to collect grab samples in various parts of a room in the Building 371 tests, but the samples were not diluted.

EXPERIMENTS, DATA TABULATION AND DISCUSSION OF RESULTS

1. Experiments in Building 371

This test series took place in Building 371, Room 3206, and was an initial effort to explore the

potential of this new approach to air tracing. This room was chosen, because production work was limited and it was the only location for the release of large amounts of tracer smoke.² Figure 3 shows the layout of the glovebox lines and ventilating system. The air enters the room through a series of ceiling diffusers in the form of perforated sheet metal boxes. Exhausts are at floor level below the gloveboxes. The air handling system is designed to produce nearly laminar down flow, but with the gloveboxes taking up considerable space, turbulence can be expected.

The effect of air change rate on tracer concentration was of major interest, as well as any changes in tracer dispersion patterns. Past data suggested that

FIGURE 3. Building 371, Room 3206 Ventilating System Layout

higher air change rates confine the spread of contamination more.¹ The tracer aerosol for these tests was released from the top of a glovebox at a 7-ft height near the east end of the room as shown in Figure 3. A long hose on the tracer detector was used to probe the tracer concentration at various points and the syringe grab sample procedure was used for points not easily accessible.

Figure 4 summarizes tracer test data from Building 371, Room 3206, at 5 and 15 air changes. The bar graphs are superimposed upon the glovebox-line layout of the room. The base of a set of bars shows the relative position of where the tracer sample was taken in the room. The height of the bar indicates the percent of the particles that were released at the source, and detected at the sampling

FIGURE 4. Equilibrium Concentration of Tracer in Building 371, Room 3206 at Different Air Changes. Source at east end.

point. This is based on the calculation of the number of tracer particles per liter at the source and at the detector. Also, the height at which the samples were taken is indicated by the coding of the bar; i.e., horizontal-lined bars indicate 6-ft samples; and solid or clear bars indicate 12-ft samples.

For a quick overview, compare the relative height of the differently coded bars. Keep in mind that they are referenced to a log scale for the relative concentration values (%).

The tracer concentrations are higher for the lower air change rate. Specifically, at 6 ft the concentrations at 5 changes are, on the average, about 4.4 ± 1.8 times higher than 15 changes. This set of runs (Runs 1 and 2) compares measurements at the airheads (6 ft) only. The samples for Run 3 at 6 ft were taken with the syringe procedure at the sides of the gloveboxes, not at the airheads, and out in the bays. These values follow about the same trends as the 6-ft samples for Runs 1 and 2. The samples taken at 12 ft are of interest, because they do not differ too much from the tests at 6 ft. This indicates that considerable turbulence exists in the room. The clean air enters the room from a series of diffusers in the ceiling and is exhausted through outlets on the floor. Laminar down flow does not exist. The 12-ft level is within a few feet of the ceiling.

The higher air change rate reduced the tracer concentration proportionally to the airflow increase. The other result of interest was the time it took for the tracer to reach equilibrium and the time it took to clear out the tracer. For the first response it took about 2 to 3 min. To reach equilibrium required 15 to 20 min and the decay time was about the same.

There seems to be a decrease in tracer concentration from east to west. To place this on a quantitative basis, a linear regression line was fit to the concentration data versus distance from the source. The correlation coefficient was -0.41 , not particularly strong. The regression line indicates that the concentration decreased by a factor of 7 from Room 1 Sections 1 to 6, as shown in Figure 4.

One test was made with the source at the west end of the room to test for any difference in dispersion patterns. Figure 5 illustrates the results. Time did not allow probing to determine whether the tracer reached the east end of the room. The limited data show a reasonable reduction of tracer concentration with distance from the source toward the east. The reduction is somewhat stronger than for the previous reversed source arrangement.

There is no strong evidence from this data that the higher air flow rate provided more confinement of the tracer or simulated contaminant. Apparently, large scale turbulence at both flow rates controls the dispersion process.

2. Experiments in Building 707, Module D

Module D was of interest, because the air inlets are supplemented by perforated ceiling panels that are supposed to diffuse the incoming air into an even downward air stream. There is no evidence that indicates whether this effect has been verified by air velocity measurements at ceiling level. Similar panels are sold for office building use for appearance only and the manufacturer claims that air flow is not affected by the panels. That is, flow patterns are controlled by diffuser inlet design.

A different approach was used than the test in Building 371. The detector intake remained in one place for a dispersion test sequence, while moving the source. This was done to prevent the long sample hose used in the Building 371 tests from interfering with work in Module D, which had much more activity. The results of this dispersion survey to establish the spread of the tracer are given as the percent of source output detected at a test point; i.e., the number of particles detected over time divided by total number of particles released at the source over time.

Table 1 and Figure 6 summarize data from Building 707, Module D, collected during a general tracer survey of the room. The tracer source was moved around the whole room to the locations shown in Figure 6. The detector was located at Location 1 for most tests, except for moves to Locations 2 and 3 (see Figure 6). Detector location was found not to matter too much. Percent of source input

FIGURE 5. Air Tracer Test at 15 Changes/hr. Source at west end of room.

TABLE 1. General Survey of Flow Patterns in Building 707, Module D at 14 Air Changes: Time of Transport to Various Parts of the Module and Tracer Concentration Versus Height

Location of Source	Location of Detector	Height of Detector (ft)	Time to First Response (min)	Time to Reach Equilibrium (min)	Decay Time (min)	Percent of Source Output at Detector	Comments
A	1	3.5	3.0	8	19	1.3×10^{-2}	Ave. $(9.4 \pm 3.4) \times 10^{-3}$
A	1	3.5	3.0	10	a	1.7×10^{-2}	
B	1	3.5	5.0	11	21	1.1×10^{-2}	
B	1	8.5	2.5	15	a	9.2×10^{-3}	
B	2	8.5	a	a	a	6.8×10^{-3}	
B	3	8.5	a	a	a	1.0×10^{-2}	
B	3	0.0	a	a	a	6.8×10^{-3}	
B	1	3.5	a	a	a	9.2×10^{-3}	
B	1	3.5	a	a	a	9.2×10^{-3}	Below missing ceiling panels
C	1	1.0	4.0	19	a	5.5×10^{-3}	
C	1	1.0	4.0	a	19	5.8×10^{-3}	
D	1	1.0	8.0	a	a	4.2×10^{-3}	
E	1	1.0	6.0	17	a	1.5×10^{-3}	Excluding Loc. D
E	1	1.0	3.0	11	15	2.2×10^{-3}	
						$(8.2 \pm 4.2) \times 10^{-3}$	

a. Generator was operating continuously while at these locations. Therefore, the room was not cleared of tracer aerosol for the next test.

FIGURE 6. Module D, 707: Layout for General Survey of Air Tracer Flow Patterns

was principally a function of distance between detector and the source. The percent of source concentration detected varied no more than one order of magnitude across the length of the room, except when the source was positioned at Location D. There the detector concentration dropped almost another two orders of magnitude. A large number of ceiling panels were missing above Location D. These panels, as mentioned earlier, are perforated with small holes to force a laminar down flow into the room. The area of the missing panels could represent a low resistance path for incoming air, flooding Location D with clean air. It will be shown later, when the panels were replaced, that this was not the case. Evidently, the incoming air flow is much higher at Location D. This caused asymmetric concentrations at other locations as will be seen later.

Table 1 gives the time for the first response at a given location after tracer release. The response time did not vary much, i.e., 2.5 to 5 min on the north side of the central conveyor. Tracer released

in the southeast corner took 6 to 8 min to reach the detector in the northwest corner. To attain full equilibrium, 8 to 19 min were required. These values were erratic, and it was noticed at several locations that a steady equilibrium did not exist. There were cycles of about 5 min duration in which the concentration values varied by a factor of approximately 2. This may be related to surges in the air handling system when doors are opened. The decay times were more consistent at 15 to 21 min.

Overall, this initial survey showed that strong turbulence existed in this room, similar to Building 371. Even though, compared to Building 371, the ceiling was lower and the incoming air should have been more evenly distributed because of the ceiling tiles. The concentration values in Building 707, Module D were not too different from the experience in Building 371.

The next step was tracer tests in a more limited area involving only one glovebox bay. Figure 7

FIGURE 7. Limited Area Tracer Survey in a 707D Glovebox Bay (at Different Heights)

presents the results. The source was located on the floor in the middle of the bay. Measurements of tracer concentration were made at different levels above the floor to explore the tracer distribution toward the ceiling. The ceiling panels in this area were all intact. Nevertheless, no laminar flow patterns were observed; that is, the expected decrease in concentration as the ceiling was approached did not materialize. Actually, there was a trend of increasing concentrations by a factor of 8 as the detector intake was raised from floor to ceiling at a given location. This trend confirms the previous observation of turbulent mixing in the room. The tracer concentration was higher to the west, possibly reflecting an influx of clean air from the southeast corner of the room.

The final test series covered the effect of changing the air change rate from 14 to 10 and then to 7

changes per hour. Also, a repeat run was made at 14 changes per hour with the ceiling back in place at the southeast end of the room. Figure 8 and Table 2 summarize the results. Figure 9 defines the location of the source as it was moved around during the tests. The objective was to monitor the concentration of the tracer at the nearest SAAM for a sequence of simulated glovebox leaks. The leaks were arranged in a symmetric grouping around SAAM 31, located on the north wall above an exhaust. Location A simulated a leak at a glovebox, Location B was a bag-out port, Locations C and E were joints, and the rest were glovebox ports. The objective was to establish if the tracer concentration decreased with increasing air change rate, everything else being equal, as was the case in Building 371. However, if the tracer concentration decreases, the advantage of more contaminant dilution due to higher air flow would be negated

TABLE 2. Ventilating Rate Versus Concentration Detected at SAAM #31 Due to a Simulated Glovebox Leak

Tracer Release Position	Time to First Response, Min			Time to Reach Equilibrium, Min		
	7 Changes	10 Changes	14 Changes	7 Changes	10 Changes	14 Changes
A	2.5	4.0	3.5 (3.0) (a)	7.0	10	12 (6.0)
B	3.5	3.2	2.5 (2.7)	12	10	7.7 (8.3)
C	3.5	3.0	4.0 (--)	13	7.2	16 (--)
D	2.0	2.8	2.0 (--)	9.0	9.0	7.0 (--)
E	3.0	3.5	2.8 (2.0)	10	8.0	9.3 (5.0)
F	3.5	6.0	5.0 (2.5)	11	17	10 (7.5)
G	6.0	5.2	4.0 (3.0)	12	14	9.0 (6.0)
Average	3.4 ± 1.3	4.0 ± 1.2	3.4 ± 1.0 (2.6 ± 4.2)	11 ± 2.2	11 ± 3.6	10 ± 3.3 (6.6 ± 1.3)

Tracer Release Position	Time to Decay, Min			% of Source Concentration at SAAM #31		
	7 Changes	10 Changes	14 Changes	7 Changes	10 Changes	14 Changes
A	13	13	12 (8.5)	1.6×10^{-3}	1.6×10^{-3}	2.2×10^{-3} (1.3×10^{-3})
B	15	15	17 (10)	8.2×10^{-3}	8.2×10^{-3}	7.0×10^{-3} (3.6×10^{-3})
C	12	14	14 (---)	1.3×10^{-3}	1.1×10^{-3}	4.3×10^{-3} (-----)
D	13	16	16 (---)	1.9×10^{-2}	5.9×10^{-3}	1.2×10^{-2} (-----)
E	18	15	18 (11)	6.5×10^{-3}	6.7×10^{-3}	1.0×10^{-2} (5.7×10^{-4})
F	14	14	16 (9.0)	9.4×10^{-4}	2.7×10^{-4}	4.7×10^{-4} (3.0×10^{-4})
G	10	17	15 (8.0)	3.1×10^{-4}	2.9×10^{-4}	2.8×10^{-4} (3.8×10^{-4})

Average	14 ± 2.5	15 ± 1.3	15 ± 2.0 (9.4 ± 1.3)	$(5.4 \pm 6.7) \times 10^{-3}$	$(3.0 \pm 2.8) \times 10^{-3}$	$(5.2 \pm 4.6) \times 10^{-3}$ $(1.2 \pm 1.4) \times 10^{-3}$
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$r = 0.88$

$r = 0.95$

$r = 0.40$

a. Values in parentheses are for a repeat of 14 changes/hr, but with the ceiling tiles at the SE end of the room installed.

FIGURE 8. Effect of Air Rate Change on Tracer Concentration at SAAM #31

FIGURE 9. Building 707, Module D: Layout for SAAM Air Tracer Tests

by the fact that the SAAM has to sample a larger air volume before responding.

Figure 8 graphically summarizes the results. No clear effect of air change rate on concentration was found. This may be related to the following observation. There is an asymmetric response to tracer released at Locations F and G; i.e., a more than one order of magnitude drop in sampler concentration compared to the similar sources at Locations A and B. This supports the idea that more air flowed from the ceiling vent in the southeast corner and then spread to the west and down to the floor exhausts.

Originally, we thought that replacing the ceiling tiles in the southeast corner of the room would result in a uniform concentration pattern. The tiles were replaced, but as Table 2 and Figure 8 show this did not produce a symmetric concentration pattern. These results make it clear that air velocity and direction measurements must accompany aerosol tracer tests to achieve a full

understanding of contaminant dispersion. The results confirm that the response of SAAM 31, contrary to expectations, is not materially affected by the air change rate in Module D.

Table 2 provides a quantitative summary of the above conclusions. First of all, flow patterns were not affected by air change rates. This is shown by the linear correlation coefficients (see the r values in Table 2) for the concentrations at the various locations for each of the different air change rates. The r 's indicate a high degree of correlation. The coefficients are 0.88 and 0.95 for 7 and 10 changes respectively, referenced against 14 changes. The coefficient for the second test series at 14 changes is only 0.40, but this series was incomplete because there was no time to collect samples at Locations C and D. The times for first response, to reach equilibrium and to decay are quite consistent for all air change rates. This also confirms the consistency of the flow patterns, being the same at all air change rates.

3. Selection of Airhead Height for Maximum Response to Contaminants at Breathing Zone Level

Preliminary tests were conducted with this new tracer technique to determine if an optimum height exists for the location of airheads on a glovebox. The objective was to locate the airhead to maximize response to contaminants in the breathing zone. The most likely contaminant source is a leak from a glove. A secondary criteria for airhead location is ease of accessibility for routine servicing of the filters. The airhead should not be located in a position where it interferes with the work being performed or where the filter could be damaged.

The experimental plan was to release the tracer in a glove or at a glove port and then determine tracer concentration versus potential airhead positions. It should be kept in mind that the tracer work so far was done with the detector well outside of the glovebox bay of interest. Therefore, a diluting system had to be installed on the detector, while working within 1 m or so of the release point. Also, there was no prior information that indicated whether the tracer concentration patterns would be stable on such a small scale. For instance, observations of cigarette smoke flow patterns show that filaments of the smoke move about in random patterns, before a more homogenous smoke forms at a distance from the source.

The above concern proved to be the major problem in trying to study the optimization of airhead location. Initially, the smoke tracer was released from the inside of a glove, which was extended into the box, to simulate a glove leak during a work task. The detector sampling point was Airhead 27 on Box D-80. Gloves right below the airhead and at the far end of the box were tested. The tracer concentrations varied by an order of magnitude in a 2- to 5-min oscillating pattern. Therefore, another test series was tried with the tracer release along the glove port edge. The large oscillations are believed due to glove pumping.

Tracer patterns were steadier for the first test with the tracer released at the farthest port with respect to the sampling point. However, it was still impossible to detect any effect of a person standing at the glovebox ports simulating work activity. The only trend that appears is that the detected tracer concentration increases with sampler height. That is, at 5, 6 and 7 ft respectively, a rough estimate shows that the concentration averages are 20, 35 and 45 counts/sec for the undisturbed periods, but more tests are necessary to verify this trend. The second test was at a glove port almost below the airhead. Here, strong oscillations in concentration developed; it might be argued that they were started when the experimenter moved around at the port. To verify such a conclusion, a more intensive study has to be undertaken.

The value of this preliminary study is that it points out the large temporal concentration variations that exist as an aerosol stream from a glovebox starts to mix with room air.

FUTURE WORK

Future studies must include air velocity and direction measurements to document overall air motions. Also, measurements of pressure differential fluctuations between a room and hallway and gloveboxes are of interest. Finally, simultaneous tracer measurements at a number of locations are vital to an understanding of contaminant dispersion and control. This is best accomplished by a different tracer system. Multiple ice nucleus counters are not practical because of equipment size and cost. We are proposing to use a new, simplified laser particle counter operating in the >0.5 and $>5 \mu\text{m}$ range. The detectors are small and can be multiplexed with a computerized data system. The tracer aerosol would be a water solution of sugar to produce particles just over $0.5 \mu\text{m}$. An anticipated problem is that this tracer is visible near the source. Also, as the particles disperse, background aerosol particles in the 0.5 to $5 \mu\text{m}$ range will start to dominate.

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