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EVALUATION OF A RADIOACTIVE AEROSOL SURVEILLANCE SYSTEM*

by

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ABSTRACT

Measurements of the dilution of air contaminants between worker breathing zone and area air samplers were made by releasing a test aerosol in a workroom equipped with an aerosol surveillance system. These data were used to evaluate performance, and suggest improvements in design of the workroom's alarming air monitor system. It was found that a breathing zone concentration of 960 times the maximum permissible concentration in air (MPC_a) for a half-hour was required to trigger alarms of the existing monitoring system under some release conditions. Alternative air monitor placement, suggested from dilution measurements, would reduce this average triggering concentration to 351 MPC_a. Deployment of additional air monitors could further reduce the average triggering concentration to 241 MPC_a. The relation between number of monitors and triggering concentration was studied. No significant decrease in average triggering concentration was noted for arrays containing greater than five monitors.

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INTRODUCTION

Potential contamination of the work environment must be anticipated in facilities dealing with significant quantities of toxic materials. Sporadic releases to work environment may occur without detection by workers. Routine air sampling is an essential safeguard in such facilities, alerting workers of unsafe air concentrations, providing detection of low level releases, monitoring containment and determining potential inhalation exposures.

A major consideration in design and operation of an air sampling system fulfilling these responsibilities is the relation between sampled air concentration and air concentration in the worker's breathing zone. Knowledge of this relation is necessary for meaningful interpretation of air sampling data.

This relation was investigated by releasing a test aerosol from several potential release locations in a workroom equipped with an aerosol surveillance system. Dilution measurements between worker breathing zone and sampler location were made. These data indicated important parameters in interpretation of air sampling data and suggested improvements in design of an air monitoring system.

PROCEDURE

The model used in this study is an operating aerosol surveillance system located in a glove box workroom of a plutonium handling facility. Work in this facility is concerned with research and development involving various forms of plutonium. Activities in this workroom specifically deal with $^{239}PuO_2$.

Room layout is typical of that found in facilities dealing with toxic materials (Fig. 1). All work is done inside glove boxes. Dilution ventilation is used to clear unanticipated accidental releases. The ventilation inlet is located near the ceiling, and exhausts are located on the floor opposite the inlet. Ventilation rates exhaust ~20% of room volume per minute.

The aerosol surveillance system consists of an array of eight area samplers and two alarming continuous air monitors (CAMs) (Fig. 1). Area samplers are located along glove box faces, 2 m above the floor. CAMs are located near each room air exhaust, 1 m above the floor. Sampling rate is 0.012 m^3/min for samplers and monitors.

Simulated airborne releases at glove boxes were made from 20 potential release locations in the workroom studied (Fig. 2). During release, air samples were collected with the room aerosol surveillance system. Additional air samples were collected with samplers located at both room air exhausts (Fig. 3).

Test aerosol was generated from a solution of fluorescein in NH_4OH. Fluorescein is an organic compound used to generate test aerosols in the laboratory. Its fluorescent properties permit detection of air concentrations down to 0.1 $\mu g/m^3$ under the sampling conditions used in this test program.

The aerosol generator used consists of 24 Retec nebulizers suspended in a 30-cm-diam canister partially filled with fluorescein solution. At a pressure of 1.38×10^5 Pa_{gage} an airflow of 0.132 m^3/min was exhausted through the generator and an aerosol with count median aerodynamic diameter (CMAD) = 0.35 μm and geometric standard deviation $(\sigma)_g$ = 2.1 was produced. The exit air concentration from the generator was measured to be 0.06 g/m^3. Releases were made at 1.3 m above the floor to simulate leaking from the glove. Breathing zone concentration to an individual at the release location was measured by air sampling 0.4 m above the generator exhaust. The estimated breathing zone concentration from these measurements was 2 mg/m^3. This value was used to calculate dilution factors between the worker's breathing zone and the sampler location.

Aerosol was generated during the first 15 min of a test. Collection of air samples was initiated when aerosol generation started and continued for 15 min after generation was stopped. Another test was started after the room was allowed to clear for 15 min, and clean sampling filters were placed on all samplers. Studies show that 30 min after aerosol generation has stopped, room air concentrations were 3 orders of magnitude lower than the average 30-min test concentrations. Six releases were made from each of the 20 potential release locations shown in Fig. 2.

Air sample filters from these tests were placed in bottles containing an NH_4OH solution. These solutions were analyzed using a Turner fluorometer. Blank solutions for these measurements were made by placing clean sampling filters into the NH_4OH solution.

RESULTS

Breathing zone dilution factors (BD) were calculated for each release-sampler combination by dividing breathing zone air concentration at release by air concentration at sampler. Estimates of average breathing zone dilution factor ($\overline{BD}$) and standard deviation were made over the six releases from each release location. These averages ranged from 1 to 1079 (Table I). Table II summarizes $\overline{BD}$ for each sampling location. $\overline{BD}$ averaged over all release-sampler combinations was 60. Other investigators[3-5] who studied dilution between breathing zone and area air samplers found BD to range from 0.1 to 9870 (Table III) with average BD over all release-sampler combinations varying from 0.9 to 250 (Table III). The average BD value of 60 found in this study compares favorably with other values of average BD found in Table III. These data suggest that general area air sampling may underestimate worker exposure concentration by as much as four orders of magnitude.

$\overline{BD}$s for alarming CAMs were among the highest for many of the release locations studied (Table I). Smoke tube mapping and computer modeling of room airflow indicated vertical circulation, which may explain the high dilution factor association with monitors located near room air exhausts. For rooms with such airflow patterns, placement of alarming CAMs at locations other than near room exhausts may improve detection of accidental releases.

Using $\overline{BD}$s and operating parameters of the CAMs, estimates of half-hour breathing zone concentration needed to trigger alarms (TC) were calculated for each release-sampler combination according to Eq. 1.

$$TC = (A / V) \times \overline{BD} \qquad (1)$$

where,

TC = half-hour breathing zone concentration required to trigger alarm.

A = activity required to trigger alarm.

V = volume of air sampled by monitor in a half hour.

$\overline{BD}$ = breathing zone dilution factor averaged over six releases.

TC associated with monitor arrays containing more than one monitor were determined using the lowest individual TC associated with the monitors making up the array. Table IV summarizes these calculated values and Appendix A details all individual TC values.

TC average and range over the 20 release locations were used as indicators in evaluating monitoring system performance and suggesting alternative monitor placement. Average TC for the existing monitor arrangement was 960 times the MPC_a* with TC ranging from 112 to 2499

Maximum permissible air concentration for "soluble" ^{239}Pu, (occupational exposure) 74 mbq/m^3.

MPC_a (Table IV). Inspection of TC averages and ranges associated with monitor arrays containing two monitors or less revealed several monitor combinations with TC averages and ranges more desirable than those associated with the existing monitoring system. Location D was associated with an average TC of 442 MPC_a with TC ranging from 46 to 1551 MPC_a (Table IV). A two-monitor array with monitors at locations D and NEC was associated with a TC average of 354 MPC_a and a TC range of 46 to 718 MPC_a. These data suggest that modification of the existing monitoring system could significantly reduce potential worker exposure without increasing the number of monitors or monitor maintenance.

Additional monitor deployment was investigated using values of TC for combinations of up to 12 monitors. The minimum achievable TC for any combination of monitors in the 12-sampler array was determined by averaging the lowest individual TC for each release location. This average was found to be 241 MPC_a with TC ranging from 29 to 661 MPC_a. The array associated with this average contained eight monitors (Table IV). Based on TC values, this is the optimum monitor deployment in that no monitoring improvement is obtained with addition of monitors and monitoring is worsened with fewer monitors. Improvement in monitoring was studied as a function of number of monitors by plotting minimum average TC versus number of monitors (Figure 4). Minimum average TC decreased steadily to 242 MPC_a for a five-monitor array. Only minimal decrease in TC average occurred for arrays containing greater than five monitors suggesting that little monitoring improvement is gained by deployment of greater than five monitors.

TC range was found to be a less sensitive measure of monitoring improvement than minimum average TC. TC range of optimum deployment (29 to 661 MPC_a) was associated with arrays of four monitors or greater, indicating no monitoring improvement associated with arrays of greater than four monitors. Whereas minimum average TC showed improvement associated with arrays of up to eight monitors.

DISCUSSION

Alarming air monitor systems when designed and operated properly should alert workers to evacuate areas with excessive levels of air contamination. Thus limiting exposure by reducing exposure time, increasing personnel distance from release source, and ultimately confining release to an area void of workers.

Proper design and operation requires alarms to trigger when certain air concentrations exist in the worker's breathing zone. If these TC are found unsatisfactory, alternative placement and/or deployment of additional monitors is necessary. Justification of monitor system modification may be evaluated by determining relative monitoring improvement based on the minimum achievable average TC for a given array of samplers. In this study, average TC associated with the existing monitoring system was almost four times minimum achievable average TC. Average TC could be lowered to less than two times minimum achievable average TC with alternative monitor placement. With deployment of five monitors, minimum average TC was found to be approximately equal to the minimum achievable average TC.

These studies indicate that placement of CAMs at locations other than near room air exhausts may significantly improve air monitoring in workrooms where circulating airflows perturb clearance of air contaminants. Qualitative evaluation of monitoring performance is possible using data from mapping of room airflows. In this study, circulating airflows that would carry air contaminants away from room air exhausts indicated that alternative placement could significantly improve monitoring. Mapping of room airflow patterns may be used to isolate workrooms with air monitoring systems warranting closer study.

SUMMARY

Evaluation of an aerosol surveillance system was performed by releasing a test aerosol from several potential release locations in a glove box workroom. Dilution measurements were made between worker breathing zone and area air samplers. These measurements compared favorably with similar measurements made by other investigators.

Dilution measurements were used to calculate half-hour breathing zone concentrations required to trigger alarming CAMs. The average TC associated with the existing monitor arrangement was 960 MPC_a. Alternative monitor placement, suggested by TC values, was shown to be capable of reducing average TC to 354 MPC_a. The minimum achievable average TC with the surveillance system's sampler array was 241 MPC_a.

Test aerosol release studies provide useful information in design and operation of aerosol surveillance systems. TC values must be known to ensure that alarms are sounded in time to prevent excessive worker exposure. If TC values are found unsatisfactory, alternative monitor placement may be suggested from the results of these studies. The relation between number of monitors and minimum average TC can be used to provide a basis for evaluating monitor system improvement.

The usefulness of test aerosol release studies is limited by the sampler array tested. Results from these studies may not be used to evaluate monitors outside this sampler array. Methods of predicting release dispersion are needed for optimizing design of new systems and suggesting modifications in existing systems. Test aerosol release studies will be used in confirming general models being developed for prediction of release dispersion.

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Fig. 1. Scaled diagram of workroom showing position of ventilation system components and aerosol sampling system components. Asterisks indicate location of CAMs (CAMs).

Fig. 2. Numbered release locations used in test aerosol release studies. Release locations are indicated with asterisks.

Fig. 3. Sampler designations used in test aerosol release studies. Asterisks indicate location of CAMs (CAMs) used in the study.

Fig. 4. Plot of minimum triggering concentration vs number of monitors.

TABLE I

AVERAGE BREATHING ZONE DILUTION FACTORS ($\overline{BD}$)

Samplers	Release Locations 1	2	3	4	5	6	7	8	9	10
A	5.7 ± 0.3*	7.1 ±2.1	7.5 ± 2.3	16 ± 5.8	40 ± 11.	151 ± 55	13 ± 5.2	2.6 ± 0.3	7.3 ± 3.6	26 ± 11
B	6.0 ± 0.7	9.4 ± 3.9	6.5 ± 0.3	10 ± 3.6	28 ± 5.5	132 ± 89	22 ± 0.9	15 ± 3.3	9.4 ± 1.3	15 ± 4.6
C	8.0 ± 0.3	11 ± 2.3	5.1 ± 0.4	8.5 ± 1.2	33 ± 9.0	45 ± 15	29 ± 2.7	28 ± 4.5	24 ± 5.7	32 ± 4.4
D	7.4 ± 4	15 ± 7.6	6.3 ± 1.0	6.9 ± 0.8	25 ± 5.6	54 ± 25	18 ± 4.0	17 ± 5.6	11 ± 2.3	18 ± 2.9
E	6.6 ± 0.2	7.4 ± 1.3	19 ± 12	12 ±2.3	22 ± 0.6	23 ± 23	3[illegible] ± 8.7	41 ± 3.9	38 ± 7.0	41 ± 8.6
F	6.0 ± 0.6	6.4 ± 1.1	34 ± 14	15 ± 3.8	34 ± 30	338 ± 128	40 ± 9.2	49 ± 2.8	43 ± 2.7	48 ± 10
G	4.9 ± 0.1	5.9 ± 0.8	6.0 ± 0.7	15 ± 6.3	71 ± 16	466 ± 190	36 ± 13	50 ± 6.6	44 ± 2.2	49 ± 12
H	2.6 ± 0.9	2.9 ± 1.3	5.7 ± 1.1	20 ± 8.7	119 ± 54	1079 ± 384	44 ± 26	96 ± 11	79 ± 34	102 ± 23
NEC	11 ± 0.5	13 ± 5.0	11 ± 2.3	18 ± 2.6	32 ± 10	23 ± 5.1	43 ± 11	54. ± 7.4	53 ± 4.1	48 ± 15
SEC	11 ± 2.1	12 ± 3.7	11 ± 4.0	19 ± 3.0	3.9 ± 8.7	31 ± 7.2	55 ± 8.0	5.4 ± 4.1	64 ± 40	57 ± 15
NEX	9.8 ± 0.7	10 ± 1.7	8.6 ± 2.4	36 ± 33	43 ± 13	25 ± 11	36 ± 36	61 ± 34	64 ± 40	57 ± 15
SEX	11 ± 1.0	13 ± 5.6	15 ± 5.4	25 ± 6.4	69 ± 36	365 ± 456	60 ± 20	89 ± 19	69 ± 22	61 ± 8.3

Sampler	11	12	13	14	15	16	17	18	19	20
A	68 ± 39	158 ± 64	148 ± 60	102 ± 49	41 ± 24	46 ± 21	63 ± 15	8.6 ± 2.5	19 ± 10	68 ± 20
B	33 ± 8.2	78 ± 31	55 ± 18	46 ± 25	24 ± 13	31 ± 10	1 ± 0.2	8.4 ± 1.4	1.3 ± 3.2	50 ± 21
C	31 ± 13	38 ± 5.2	104 ± 142	32 ± 16	23 ± 8.1	41 ± 4.7	28 ± 4.6	8.9 ± 0.7	6.4 ± 0.6	4 ± 7.1
D	13 ± 2.0	1.6 ± 2.0	6.3 ± 19	23 ± 9.2	11 ± 2.4	13 ± 2.0	24 ± 3.3	9.0 ± 1.3	6.2 ± 0.4	22 ± 10
E	63 ± 26	150 ± 25	215 ± 18	62 ± 18	61 ± 22	66 ± 12	59 ± 11	15 ± 2.7	12 ± 1.7	23 ± 0.7
F	83 ± 32	194 ± 36	236 ± 25	76 ± 21	72 ± 20	83 ± 41	68 ± 13	16 ± 1.0	13 ± 1.2	26 ± 7.0
G	118 ± 45	240 ± 51	256 ± 45	110 ± 38	86 ± 22	79 ± 16	73 ± 13	12 ± 2.1	12 ± 1.4	46 ± 18
H	224 ± 83	469 ± 114	546 ± 125	194 ± 90	196 ± 39	165 ± 34	124 ± 37	6.7 ± 1.9	10 ± 0.7	51 ± 33
NEC	58 ± 27	41 ± 34	87 ± 61	85 ± 25	42 ± 28	84 ± 29	9.6 ± 1.4	14 ± 2.1	11 ± 1.1	8.5 ± 1.9
SEC	84 ± 41	217 ± 43	268 ± 98	80 ± 25	92 ± 35	90 ± 23	68 ± 19	54 ± 78	18 ± 2.2	20 ± 7.2
NEX	45 ± 49	66 ± 73	47 ± 30	28 ± 8.9	23 ± 9.6	21 ± 6.9	11 ± 3.5	13 ± 4.6	8.5 ± 3.7	23 ± 12
SEX	200 ± 252	208 ± 46	356 ± 128	83 ± 25	86 ± 18	162 ± 166	143 ± 146	17 ± 1.8	12 ± 1.3	18 ± 12

*Standard deviation estimate over six releases.

TABLE II

AVERAGE AND RANGE OF AVERAGE BREATHING ZONE DILUTION FACTORS (BD) OVER ALL RELEASE LOCATIONS

Sampler	Breathing Zone Dilution Factor Average	Range
A	50 ± 50	2.6 - 168
B	30 ± 30	1.0 - 132
C	30 ± 20	5.1 - 104
D	20 ± 10	1.6 - 54
E	50 ± 50	6.6 - 215
F	70 ± 90	6.0 - 338
G	90 ± 110	4.9 - 466
H	180 ± 260	2.6 - 1079
NEC	40 ± 30	8.5 - 87
SEC	60 ± 70	3.9 - 268
NEX	30 ± 20	8.5 - 66
SEX	100 ± 110	11 - 365

TABLE III

DILUTION FACTORS BETWEEN BREATHING ZONE AND GENERAL AREA SAMPLERS

Breathing Zone Dilution Factor		
Average	Range	Source
0.9		Breslin[1]
5		Brunskill[2]
10	0.1 - 9870	Caldwell[3]
250		Gonzales[4]
	0.1 - 300	Lister[5]
	1.5 - 50	Schulte[6]
40		Sherwood[7]
	3 - 301	Langmead[8]
60	1 - 1079	Scripsick

TABLE IV

TRIGGERING CONCENTRATION FOR VARIOUS MONITOR ARRAYS

No. of Monitors	Monitor Locations	Triggering Concentrations-MPC_a[a] Average	Range
1	D	442 ± 326	46 - 1551
1	NEC	1070 ± 770	244 - 2499
1	SEC	1840 ± 1980	112 - 7699
2	NEC-SEC	960 ± 810	112 - 2499
2	D-NEC	354 ± 185	46 - 718
8	A-B-C-D E-H-NEC-SEC	241 ± 190	29 - 661

[a] Based on the maximum permissible airborne concentration for "soluble" ^{239}Pu, (occupational exposure) of 74 mbq/m^3.

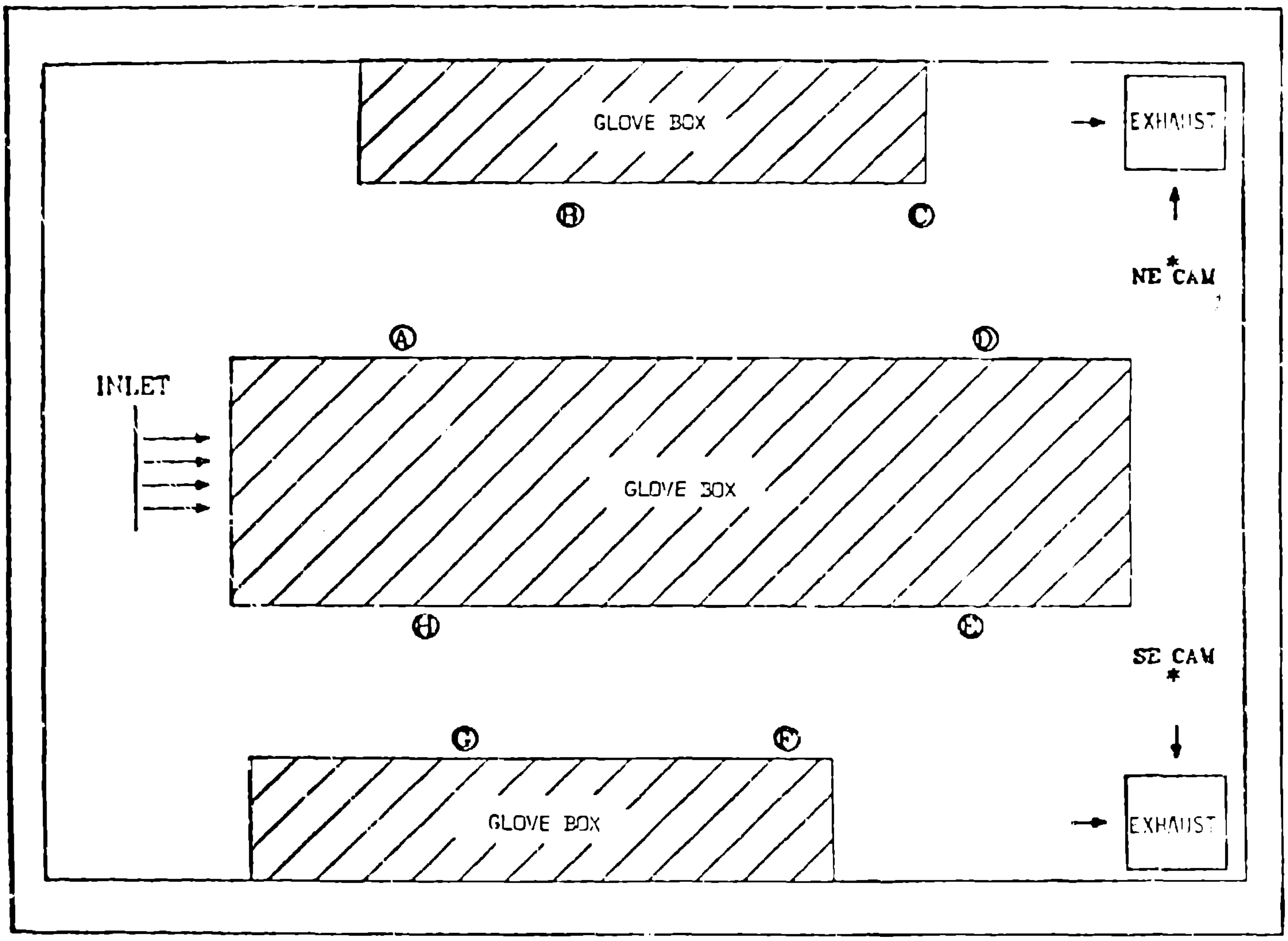

Fig. 1. Scaled diagram of workroom showing position of ventilation system components and aerosol sampling system components. Asterisks indicate location of continuous air monitors (CAMs).

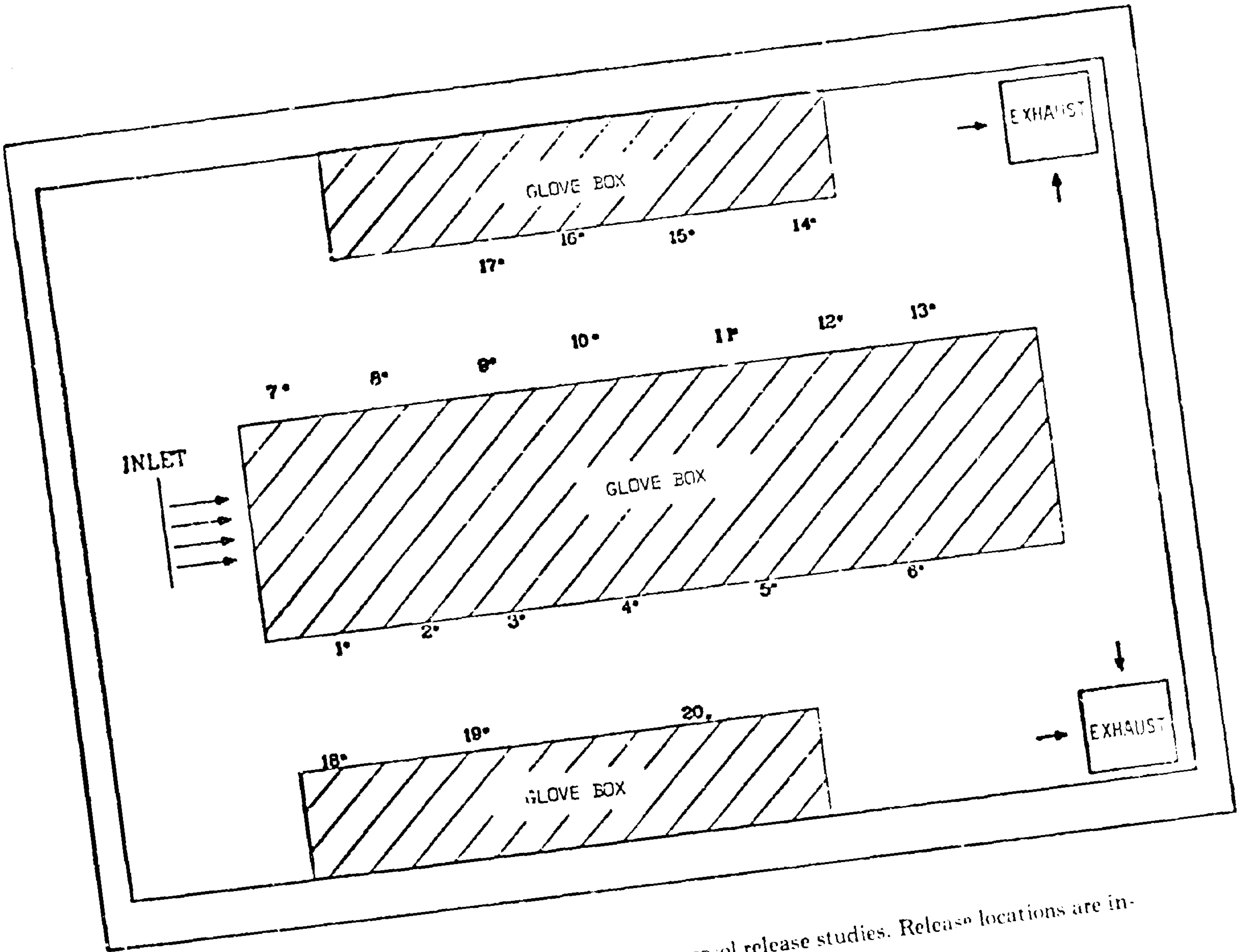

Fig. 2. Numbered release locations used in test aerosol release studies. Release locations are indicated with asterisks.

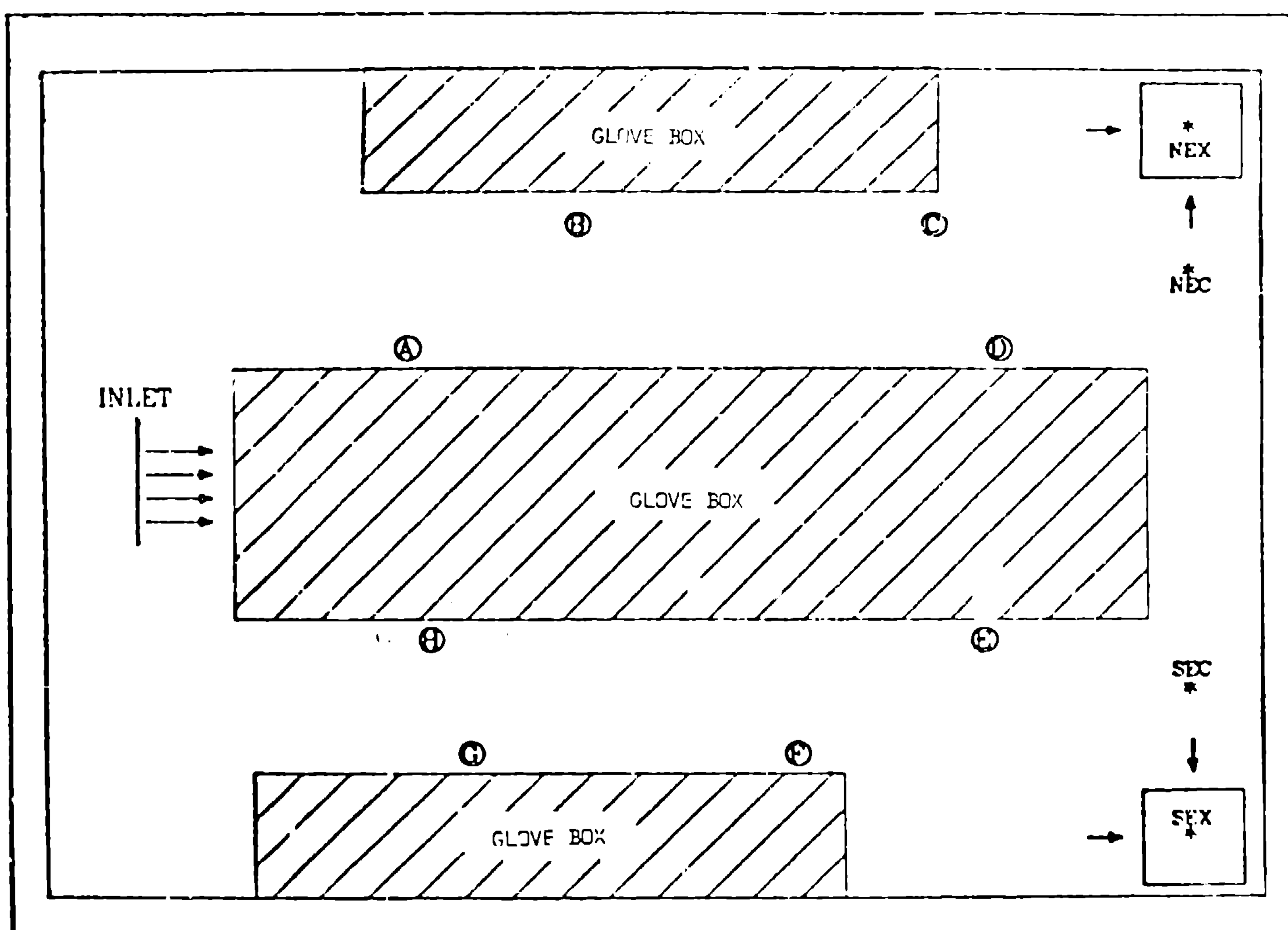

Fig. 3. Sampler designations used in test aerosol release studies. Asterisks indicate location of continuous air monitors (CAMs) used in the study.

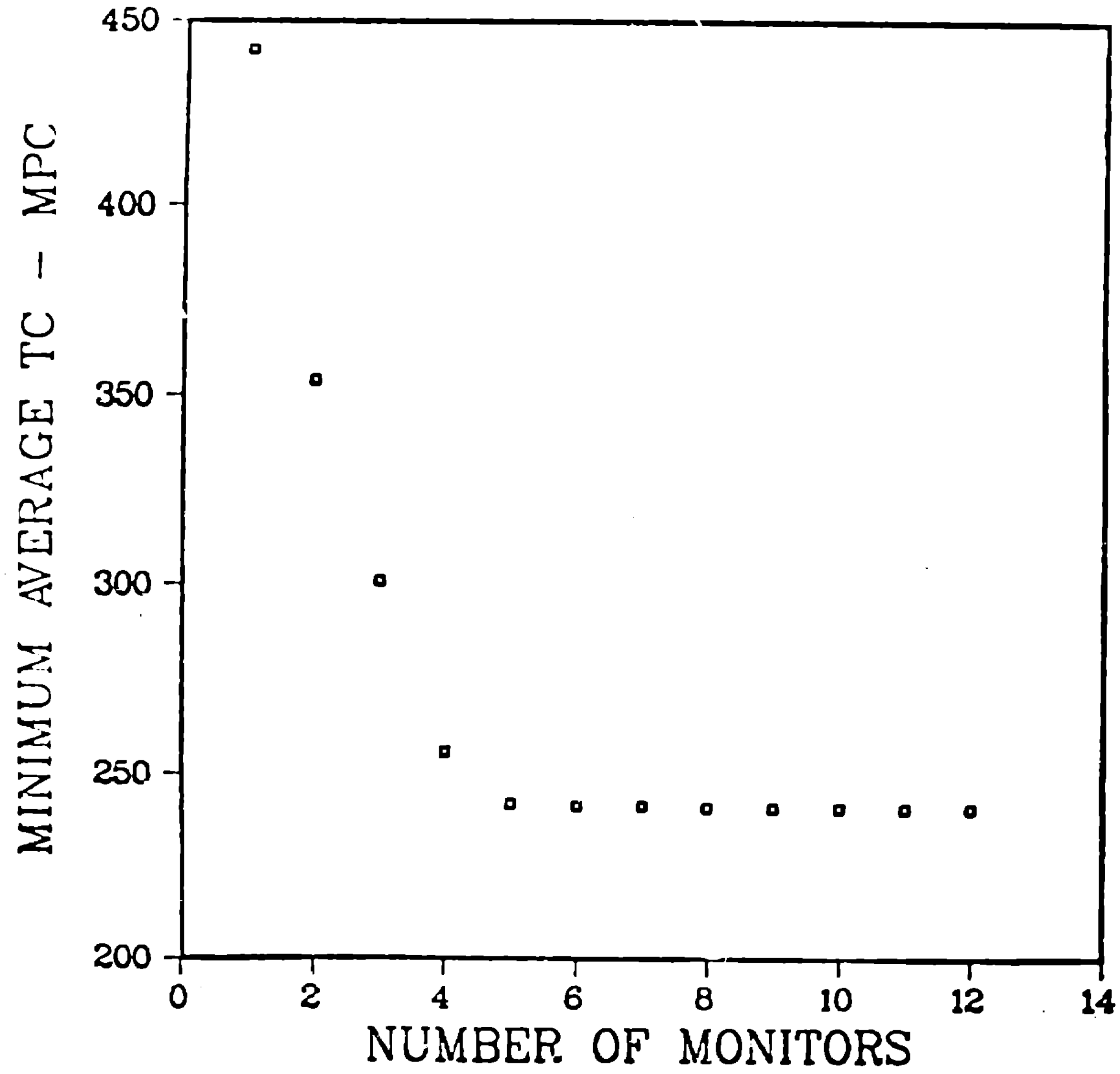

Fig. 4. Plot of minimum triggering concentration vs number of monitors.

APPENDIX A

TRIGGERING CONCENTRATION FOR VARIOUS COMBINATIONS OF SAMPLER AND RELEASE POINTS - MPC_a^a

Release Location	A	B	C	D	E	F	G	H	NEC	SEC	NEC	SEX
1	164	172	230	213	19[illegible]	172	141	75	316	316	282	316
2	204	270	316	431		184	169	83	373	345	287	373
3	215	187	147	181		977	172	164	316	316	247	431
4	460	287	244	198		431	431	575	517	546	1034	718
5	1140	804	948	718	632	977	2040	3419	919	112	1235	1982
6	4338	3792	1293	1551	661	9710	13387	30997	661	891	718	10485
7	373	632	838	517	1005	1149	1034	1264	1235	1580	1034	1724
8	75	431	804	488	1173	1408	1436	2758	1551	155	1465	2557
9	210	270	639	316	1002	1235	1264	2269	1523	1839	1839	1982
10	747	431	919	517	1178	1379	1408	2930	1379	1637	1637	1752
11	1953	948	891	373	1810	2334	3390	6435	1666	2413	1293	5745
12	4226	2241	1092	46	4309	5573	6895	13473	1178	6234	1896	5975
13	4252	1580	2928	181	6176	6780	7354	15685	2499	7699	1350	10227
14	2930	1321	919	661	1781	2183	3160	5573	2442	2298	804	2384
15	1178	698	661	316	1752	2068	2471	5631	1207	2643	661	2471
16	1321	891	1178	373	1896	2384	2269	4740	2413	2585	603	4654
17	1840	29	804	689	1695	1953	2097	3562	276	2528	316	4108
18	247	241	256	259	431	460	345	192	402	1551	373	488
19	546	37	184	178	345	373	345	287	316	517	244	345
20	1953	1436	689	632	661	747	1321	1752	244	575	661	517

[a] Based on the maximum permissible airborne concentration for "soluble" ^{239}Pu (occupational exposure) of 74 mbq/m^3.

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