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J. A. Glissmeyer
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Prepared for the U.S. Army
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Pacific Northwest Laboratory
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SUMMARY

The performance of an air-sampling system for a large-caliber depleted uranium (DU) penetrator firing range was tested during the ten initial test shots at the range. The range's target bay is enclosed and ventilated with fresh air for worker protection. The ventilation air is filtered to remove DU particles before discharge. The air-sampling system includes continuous real-time dust concentration monitors inside the target bay and at the ventilation air discharge. After the ventilation system achieves a low dust concentration in the target bay following a test shot, the bay doors are opened and two additional dust-concentration monitors are used inside, one with a 30-min sampling interval and the other with a 2-min interval. Additionally, particle samples are collected from the air discharge into membrane filters for quantitative analysis of radionuclides.

The main test objectives were: 1) to determine the bias between the monitor readings and actual DU concentrations and 2) to determine if the target bay real-time monitor tracks a decaying dust concentration as seen following a test firing. The test procedure was to operate both total and respirable airborne particle samplers adjacent to both target bay monitors for a series of ten test firings. A series of air samples was also sequentially taken after the test firings adjacent to the target bay real-time dust monitor. Exhaust particle samples were collected for each test shot. Particle samples were analyzed for gross alpha, gross beta, and uranium content. The sample analyses were then used to compare against the monitor readouts.

The analysis of the rate of concentration depletion as determined by the sequential samples showed good correlation (0.977), with the target bay real-time monitor indicating that the monitor accurately indicates the rate of change in DU concentration. The real-time monitor readings are generally somewhat lower than the DU concentrations. Average concentration from this monitor did not correlate with either the long-term total or respirable sampler DU concentrations. Therefore, to more accurately estimate worker exposure, long-term particle samplers in the workplace are recommended. Of the other target bay dust monitors, the monitor used to quickly confirm a low dust concentration

when the door is opened correlated well (0.810) with the real-time monitor. The other target bay dust monitor did not correlate with either the other monitors or the air samples; its use should be discontinued.

In the ventilation discharge, the long-term average monitor readings did not correlate very well with DU concentrations, probably because the concentrations were very close to the instrument's zero and were on the order of noise and zero drift. The exhaust monitor detected a dust discharge for each test firing usually lasting <20 min and sometimes exceeding the weekly average control limit. The accuracy of the monitor's response to these brief emissions was not tested.

Smearable surface-contamination samples from 33 locations inside the target bay were obtained and analyzed. The highest contamination was located on the equipment on the gravel floor and the exhaust air intake. The average (over the 10 rounds) concentrations in the smears varied by a factor of ten between locations. The location air-intake contamination increased over the first three rounds. Contamination was reduced by a low-pressure water spray washdown to about the same concentration as after the second round, then remained at about twice the level as after the third round for rounds 4 through 10.

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The objective of this report is to evaluate the performance of an air-monitoring system at the Ford's Farm Range where large-caliber depleted uranium (DU) munitions are test fired. The range is located at Aberdeen Proving Ground, Maryland, and is operated by the U.S. Army Material Testing Directorate (MTD). The target bay houses the test target and is continuously ventilated with fresh air to control worker exposure to inhalable DU-containing particles. The ventilation air is filtered to remove DU-containing particles prior to discharging the air.

A radiation monitoring program, including air monitoring, is required for worker protection and effluent control. The objectives of the target bay air-monitoring system are to:

- collect a representative sample of the particulate effluent for subsequent radionuclide analysis
- continuously monitor the particles present in the exhaust for loss of filter integrity
- indicate when the particle concentration in the enclosure after a test firing has decreased to a level safe for personnel entry
- indicate, while personnel are in the enclosure, when the concentration in the workplace exceeds a set action level
- record the particle concentration in exhaust and workplace.

Experiments were conducted in 1980 during the first ten DU test firings at the range to test whether these objectives were achieved. This report details the experimental method and the results of the data analyses. Additionally this report analyzes surface-contamination data collected by MTD concurrently with these experiments.

2.0 TEST PROCEDURES

The air-monitoring system for the Ford's Farm target bay has been described in detail by Glissmeyer and Halverson (1980). The test procedure was described initially in the application (1980) to the U.S. Nuclear Regulatory Commission for operation of the range. These two topics will be summarized below.

2.1 DESCRIPTION OF AIR-SAMPLING SYSTEM

Air sampling is performed both at the workplace inside the target bay and in the ventilation exhaust. The five sampling instruments and their purposes are as follows:

- exhaust sampler for collecting representative samples of particles in the filtered exhaust air for subsequent radionuclide analysis
- exhaust monitor for detecting a loss of effective air filtration
- inlet monitor at the inlet of the ventilation duct in the enclosure for indicating the decline of particle air concentration in the enclosure after a test firing or a concentration increase when the enclosure is occupied
- workplace monitor to indicate when the airborne uranium concentration in the enclosure, when it is occupied, exceeds a set level
- back-up sampler used to quickly measure air concentration in any location when other systems fail or to verify that the enclosure is safe for personnel entry.

The instruments are located in the target bay as shown in the plan view, Figure 2.1.

The exhaust sampler collects particles on membrane filters[(a)] contained in two in-stack filter holders located in regions of average velocity in the fan discharge as seen in Figure 2.2. Sampler flow rate (56.6 standard liters per

(a) 47 mm diameter, 3 micron pore, Model AN-3000, Gelman Sciences, Inc., Ann Arbor, Michigan.

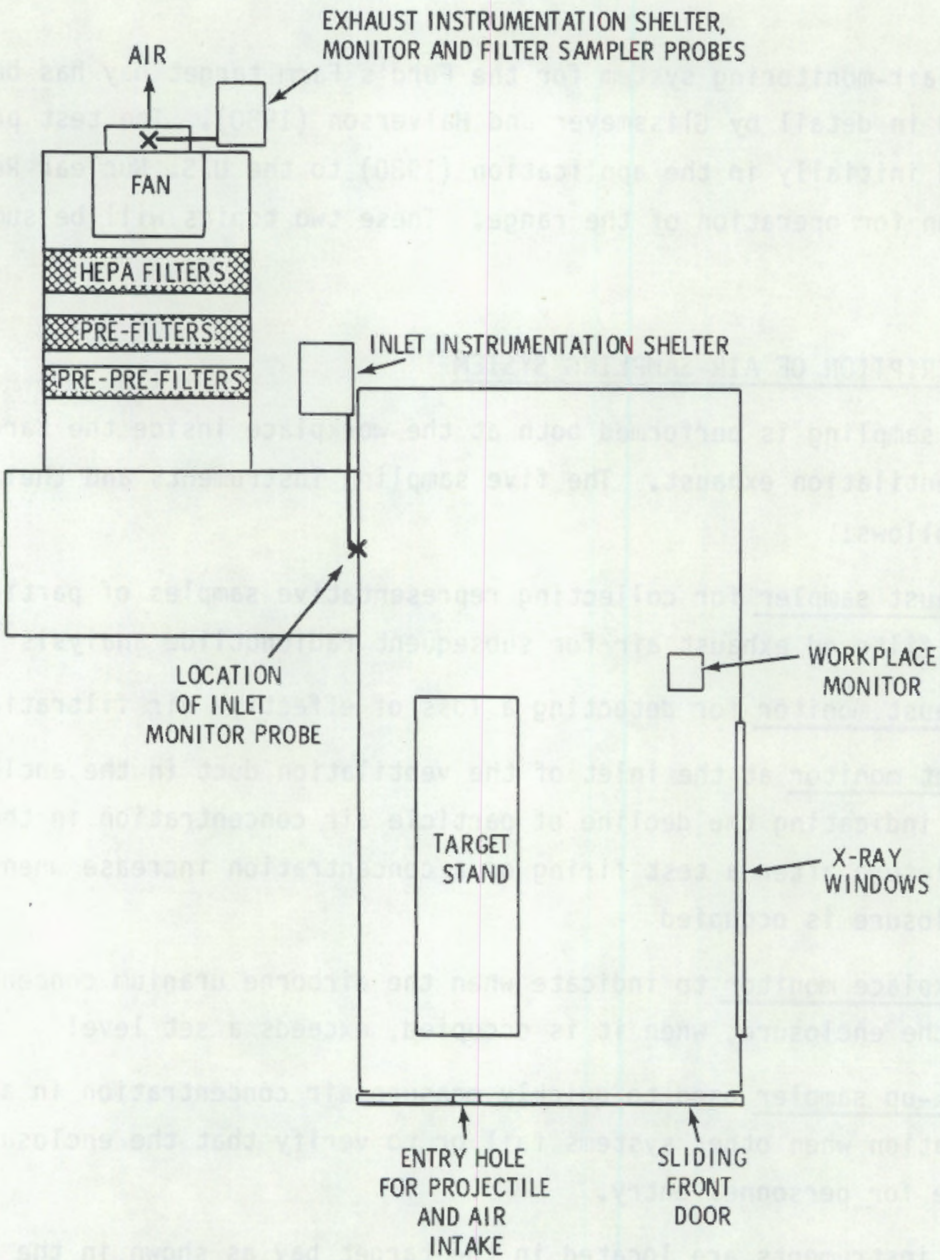

FIGURE 2.1. Top View of Target Enclosure and Location of Samplers (drawing not to scale; enclosure is ~20 ft by 40 ft)

minute [slpm] each) and nozzle sizes were selected for isokinetic sampling. The filter holders are designated as left and right reflecting their relative position when viewed from the duct discharge. The sampler is operated concurrently with the ventilation system, and samples are changed weekly.

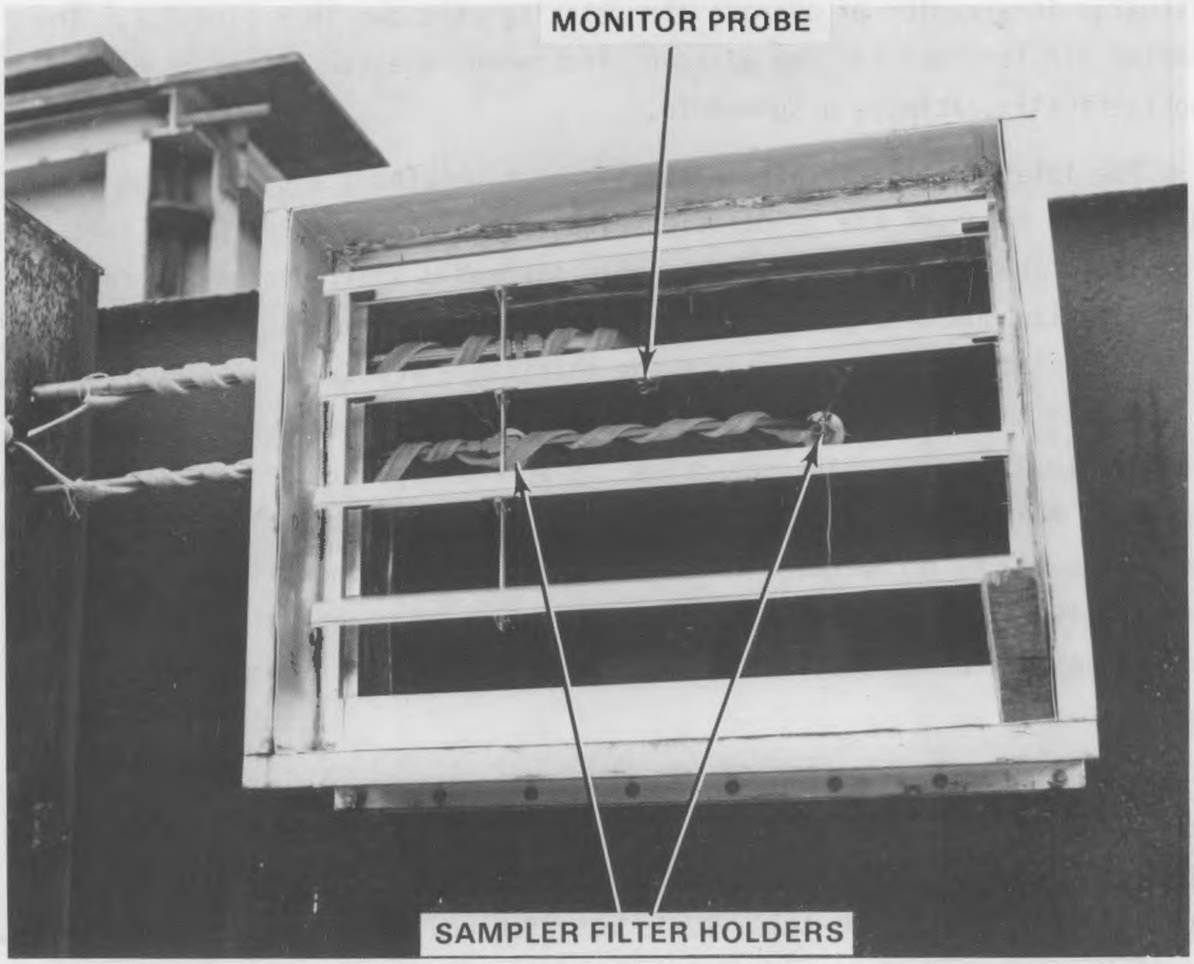

FIGURE 2.2. Sampler and Monitor Locations in Fan Discharge

The exhaust monitor is a real-time aerosol monitor (RAM-1)[(a)] used to indicate change in particle concentration such as might occur when a ventilation filter fails. The instrument, which operates on a light-scattering principle, does not distinguish DU from other dusts. Its measurement should give a conservative estimate of radiological hazard. The output of the instrument is continuously recorded and alarms are activated when a concentration limit is exceeded. An air sample is withdrawn isokinetically from the fan

(a) Product of GCA Incorporated, Bedform, Massachusetts.

discharge in a region of average air velocity as shown in Figure 2.2. The sampled air is piped into an adjacent instrument shelter where the RAM-1 isokinetically extracts a subsample.

The inlet monitor is also a RAM-1, which obtains its sample from a manifold on the front of the ventilation exhaust port in the target bay (see Figure 2.1). The manifold draws its sample through a small cyclone operated at a particle-size cutpoint of 3.5 microns aerodynamic equivalent diameter (AED)[a] so the sampled particle represents the respirable fraction. The monitor output is recorded on a strip chart that activates an alarm when a control limit is exceeded (0.05 mg/m^3). The advertised measurement precision is ±0.005 mg/m^3. The inlet monitor is operated concurrently with the ventilation system or when the target bay is occupied. The sampling manifold is back-flushed with clean air briefly during the test firing. When the inlet monitor indicates an acceptable dust concentration after a test firing, the target bay door is opened.

A workplace aerosol monitor is used in the target bay only when it is occupied. It is mounted on a cart, which is wheeled into the position indicated in Figure 2.1. This instrument is an RDM-301,[b] which measures dust impacted on a mylar film; thus, DU is not distinguished from the other dusts. The monitor samples air at two lpm (liters per minute) through a cyclone such that only respirable dust is monitored. Concentration measurements covered 30-min intervals for which the monitor has an advertised measurable concentration of 0.02 mg/m^3, ±25%.

The back-up sampler measures dust concentration using a piezoelectric mass sensor on which respirable particles are deposited by an electrostatic precipitator. This instrument, TSI-3500 Piezobalance,[c] is compact and portable allowing a measurement of respirable dust concentration down to 0.01 mg/m^3 at any work station with a 2 min sampling time. It is principally used to verify

(a) The diameter of a sphere of water that behaves aerodynamically the same as the real particles being sampled. The AED is an important parameter affecting a particle's behavior and its probability of being retained in the respiratory system. For spherical particles, AED = diameter x $\sqrt{\text{specific gravity}}$.
(b) Product of GCA Incorporated, Bedform, Massachusetts.
(c) Product of Thermosystems Incorporated, St. Paul, Minnesota.

an acceptable concentration in the target bay as the door is opened. The user carries the instrument and makes a 2-min walking traverse of the target bay. The advertised accuracy is ±10% of reading or ±0.01 mg/m^3, whichever is greater.

The function of each air sampler, readout, and frequency of use are summarized in Table 2.1.

TABLE 2.1. Air-Sampling Program for Ford's Farm

Function	Equipment by Function	Operation Frequency
Exhaust Air:		
1. Average concentration in exhaust air	1. and 4. Isokinetic in stack filters	In stack filters: Continuous when air exhausts, with weekly change
2. Real-time air concentration with alarm activation		
3. Continuous record of real-time air concentration	2., 3., and 4. RAM-1	Monitor: Continuous when air exhausts
4. Monitor filter integrity		
Enclosure Workplace:		
1. Safe to open door, real time	1. RAM-1	1., 2. Continuous
2. Continuous record of real-time air concentration with alarm activation	2. RAM-1	
3. Confirm safe to enter enclosure, short term	3. TSI-3500	3. When door opened
4. Short-term air concentration at fixed station with alarm actuation	4. RDM-301	4. When personnel in enclosure
5. Short-term portable workplace concentration	5. TSI-3500	5. Intermittent when personnel in enclosure

The air-sampling system described in Table 2.1 is unusual in that the concentration monitors are not specific for radioactive particles, which are the chief concern. In situations where the hazardous particles are radioactive, the typical monitoring instrumentation continuously collects a particle sample on a filter that is observed by a detector designed for alpha or beta-gamma radiation. This type of monitor then observes an integrated sample because particles are not removed from the detection geometry once they are collected. This integrated dose monitor renders it impractical for indicating decreasing as well as increasing concentrations. Also, the monitor's longer response time in detecting a low concentration following a very high concentration increases the time between test shots. We chose to use real-time or short-response-time instruments that monitor aerosol concentration rather than DU.

2.2 TEST OBJECTIVES

The general objective of the proof testing was to determine what correlations and biases exist between the response of the different monitors and DU concentrations as measured by analysis of particles collected on filters. More specific objectives were to investigate correlations between the following air concentration data:

Exhaust RAM-1	vs.	Exhaust DU Sample
Inlet RAM-1	vs.	Inlet DU as function of time
Inlet RAM-1	vs.	Inlet DU
Inlet RAM-1	vs.	Inlet respirable DU
RDM-301	vs.	Workplace DU
RDM-301	vs.	Workplace respirable DU
TSI-3500	vs.	Inlet RAM-1
TSI-3500	vs.	RDM-301

Using measurements of DU concentration as a function of time at the inlet location, we also wanted to investigate what would be a reasonable alarm set point for the Inlet RAM-1 to indicate an acceptable DU concentration according to regulatory guidelines.[a]

To obtain the needed DU concentration data, additional air-sampling equipment was operated during the first ten test firings. Total and respirable particulate samplers collecting particles on filters were operated adjacent to the inlet and workplace monitoring positions as shown in Figures 2.3, 2.4, and 2.5. Figure 2.3 also shows a device for sequentially sampling total particulates adjacent to the Inlet RAM-1.

2.2.1 Inlet Respirable Sampler

For the inlet sampler, the air first passed through a Bendix Model 240 cyclone, identical to that of the Inlet RAM-1, at a flow rate of 75 slpm to maintain a respirable cutpoint of 3.5 microns AED. Particles were collected on a membrane filter and sampled air passed to a calibrated rotameter, valve, and pump. In-line temperature and pressure gauges assisted in reading the flowmeter in terms of standard volume at 70°C and 1 atmosphere pressure.

2.2.2 Inlet and Workplace Total Particulate Samplers

The inlet and workplace total-particulate samplers consisted of a membrane filter in a holder, critical orifice, valve, and pump. The flowrate was calibrated with a filter in-place at 50.5 slpm.

(a) Code of Federal Regulations, Title 10, Part 20, Appendix B, Footnote 4 states that for soluble mixtures of DU isotopes the occupational (40 hr) and nonoccupational (168 hr) average maximum permissible concentrations (MPC) are 0.2 and 0.007 mg/m^3 of air, respectively. If the specific activity is unknown, the regulation directs the use of 3.6×10^{-7} Ci/g. The limits translated into units of radioactivity are then 7.2×10^{-11} and 2.5×10^{-12} µCi/ml, respectively. These limits are essentially the same as those stated in the regulation of ^{238}U except that the nonoccupational ^{238}U limit is 0.0083 mg/m^3 using the above specific activity. During the experiments 0.008 mg/m^3 was used as the nonoccupational limit because the 0.007 MPC did not exist at that time. The regulation assumes an individual inhales material at the concentration in which he is present.

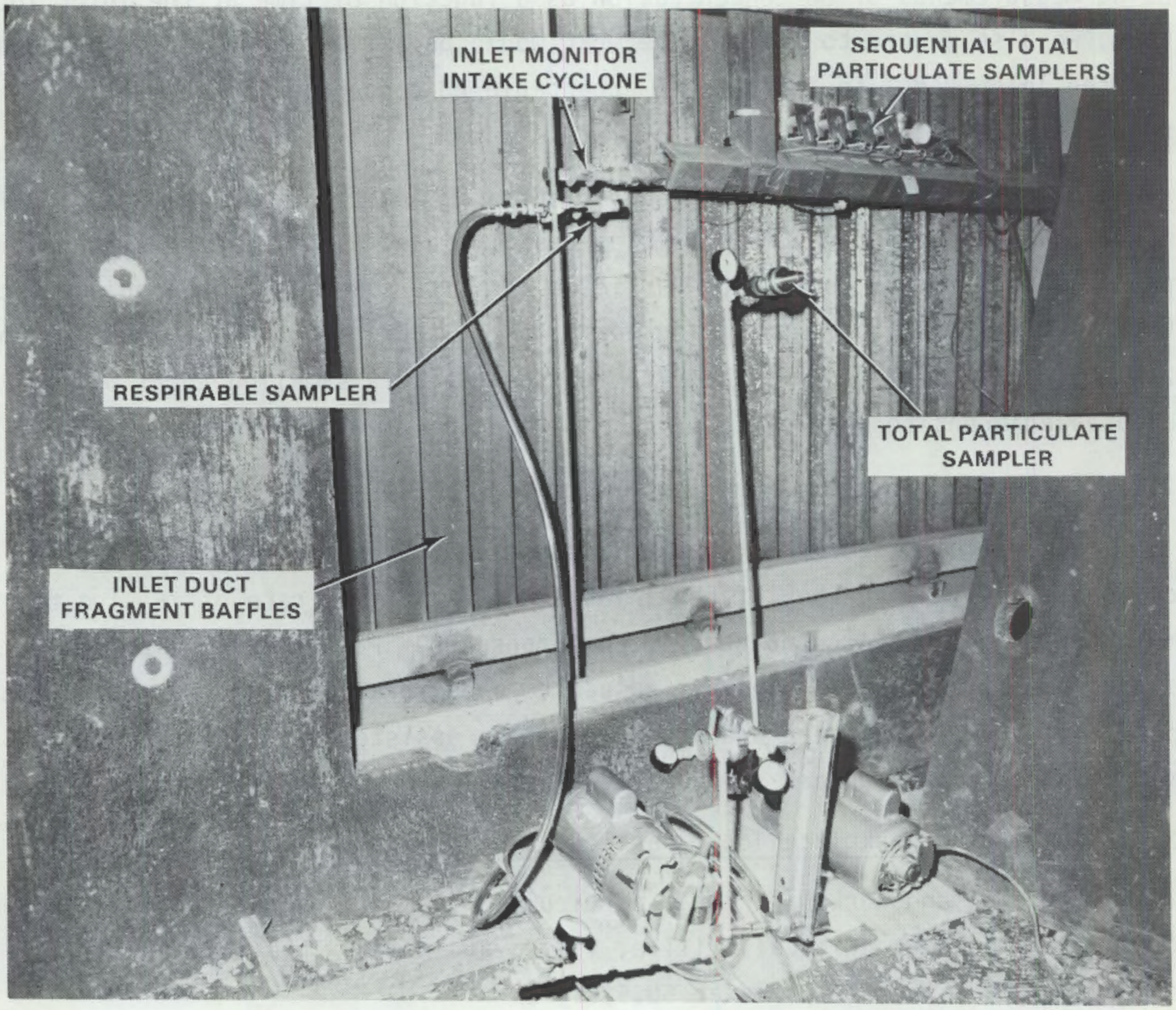

FIGURE 2.3. Air Samplers at Exhaust Duct Inlet

2.2.3 Sequential Sampler

The sequential sampler used for rounds 4 to 10 is shown in Figure 2.3. The sampler had five identical sampling heads mounted on a common manifold. Each head consisted of a membrane filter and a solenoid valve. Airflow passed through the sample filter, solenoid valve, manifold, critical orifice, valve, and a pump. A vacuum gauge was mounted on the pump and when operated at vacuum >1/2 atmosphere, the flow rate measured through each filter was determined to be 27 slpm. Each filter holder was covered with a spring-loaded flapper, which

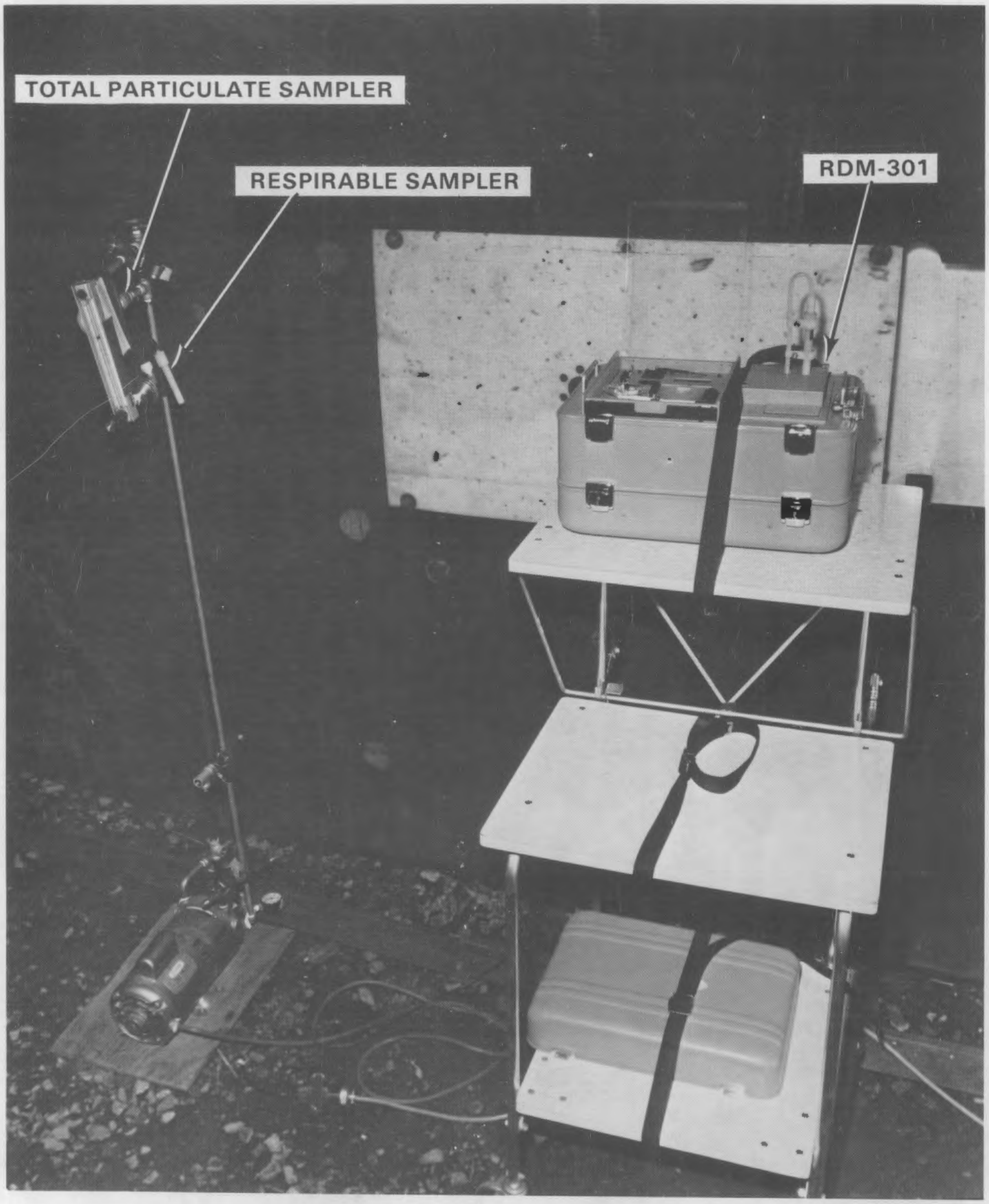

FIGURE 2.4. Workplace Samplers

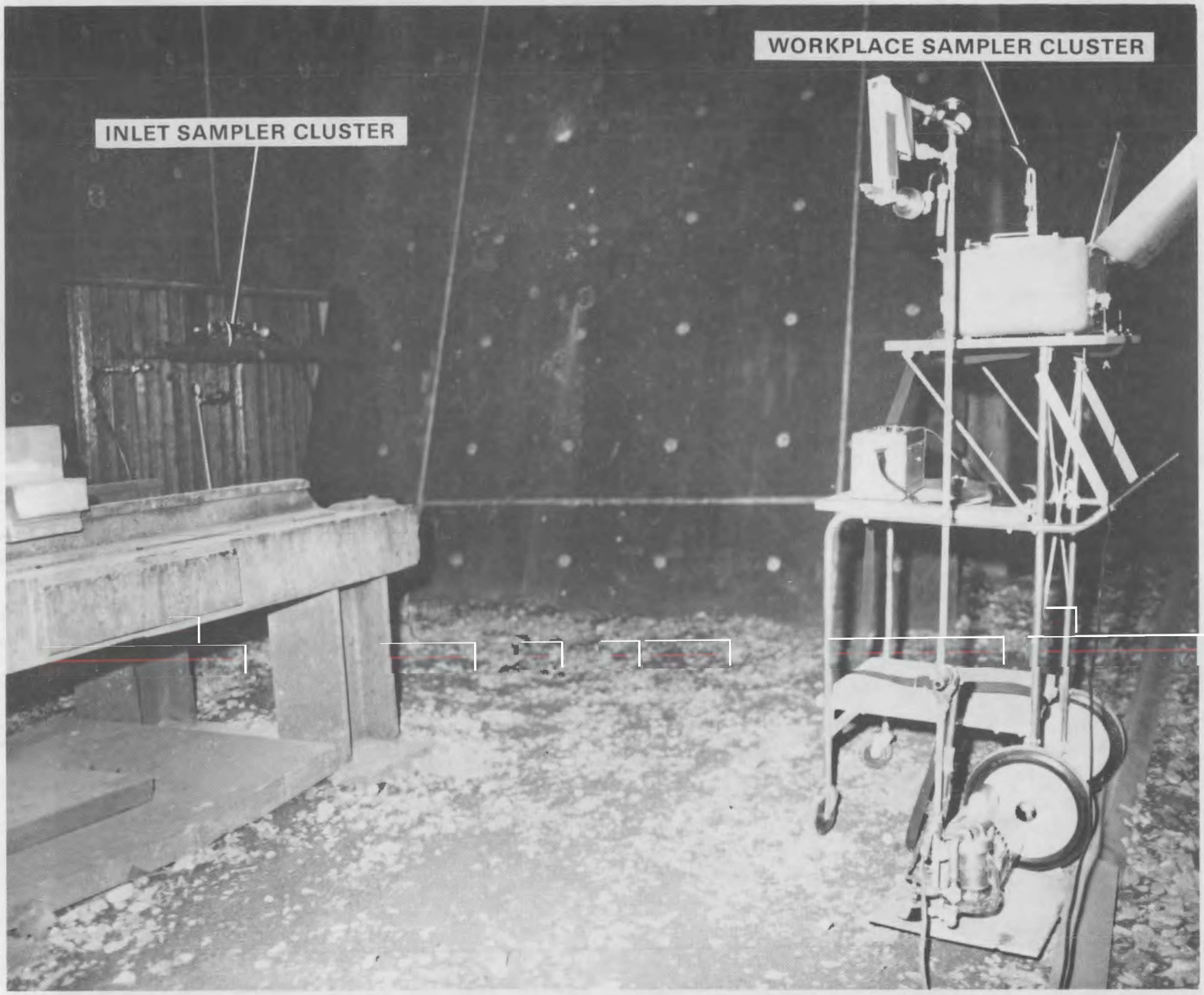

FIGURE 2.5. Locations of Workplace and Inlet Sampler Clusters

was pulled back remotely to uncover the filter for sampling. The flapper served to protect the filter from fragments.

The inlet sequential sampler used during rounds 2 and 3 had only two filter holders. Each filter holder had its own orifice and the flow rates with filters in-place were 31 and 28 slpm. No sequential sampler was used during round 1.

Because the exhaust flow rate fluctuated considerably, the inlet samplers did not sample isokinetically. During sampling with the target bay door open the air velocity at the inlet ranged from 0.75 to 3.00 m/s. The face velocity at the total particulate, sequential, and respirable samplers were 2.83, 0.35, and 1.93 m/s, respectively.

2.2.4 Workplace Respirable Sampler

Air in the workplace respirable sampler first passed through a cyclone at a rate of 2 slpm yielding a respirable particle cutpoint of 3.5 micron AED. The cyclone was a 10-mm-diameter nylon type identical to that used on the RDM-301. After passing the cyclone, respirable particles were collected on a membrane filter and the sample air went through a calibrated rotometer, valve, and pump. In-line temperature and vacuum gauges corrected flow to standard conditions. For rounds 1 to 3 the vacuum pump produced an oil smoke, which was detected by the TSI-3500 and the inlet RAM-1. The pump was then replaced.

2.3 PROCEDURE

The permanent air-sampling system was operated as described by Glissmeyer and Halverson (1980) with the exception that the exhaust air sample filters were changed out before each test firing. For rounds 1 to 4, the inlet RAM-1 was operated on only one concentration range, 0 to 2 or 0 to 20 mg/m^3, for the entire test. It read off-scale for several minutes after the shot, and the purge air was turned off. For rounds 5 to 10, the inlet RAM-1 was sequenced from the 0 to 200, 0 to 20, 0 to 2 mg/m^3 ranges to obtain data during the entire sampling period.

The target bay door was opened when the inlet RAM-1 showed a concentration below 0.2 mg/m^3 or when 30 min had elapsed after the test shot, whichever came last. A confirmatory concentration reading was taken with the TSI-3500 with a 2-min traverse inside the bay. The inlet and workplace sampler clusters were then installed and put into operation for at least 30 min. The RDM-301 was started with a sampling interval of 30 min. During the 30-min sampling period, readings were periodically taken with the TSI-3500 in the target bay.

The sequential sampler was operated as follows during rounds 4 to 10: 1) sample A for the first 5 min after the shot, 2) sample B for the second 5 min, 3) sample C for the third 5 min, 4) sample D approximately until the inlet RAM-1 read <0.2 mg/m^3, and 5) sample E until it was convenient to shut it off. During rounds 2 to 3, sample A was started within 5 min after the shot; sample B took over after the Inlet RAM-1 read <0.2 mg/m^3 and operated until the other temporary target bay samplers started.

During rounds 3 to 9 the air sampling in the target bay was done while routine target and x-ray film handling was performed. No routine activities occurred during the round 10 sampling period. Because alpha and beta sample analyses from rounds 1 and 2 showed several values below detection limits, it was decided to operate the samplers for two rounds before changing samples. This caused some data analysis problems for rounds 3 to 6. After round 6, samples were again changed every shot.

2.4 SAMPLE ANALYSIS

All sample filters except the exhaust sample were weighed before and after sampling under controlled environmental conditions. An analysis of the field blanks and other blanks showed that a collected mass under 1 to 2 mg was unmeasurable. Because most blank samples fell into that category, a further analysis of the weighing data is not addressed in this report.

Each sample filter was analyzed for gross alpha, gross beta-gamma, and uranium by an MTD contractor. Gross alpha and gross beta-gamma were determined by direct counting of the filter using standard techniques to account for background and radon/thoron daughters. Uranium was determined by sample dissolution, ion exchange on an aliquot, column elution, electroplating, and counting. Each result was reported along with the 95% confidence limits. If the confidence limits exceeded 100%, the result was reported as less than the minimum detectable level or lower limit of detection. Variability in the "less than" values was largely due to variable sample aliquot size.

The average RAM-1 readings corresponding to various time intervals were determined from the strip chart records. For long time intervals, a reading was made every 3 min. For short intervals, or when the concentration was rapidly changing, readings were made as often as every 0.3 min. Accounting for suspected zero drift during averages over 20 min was a problem. If the trace drifted below the recorder's zero, the values were interpreted as 0.000 mg/m^3 rather than as a negative concentration. If the trace baseline drifted slightly higher than the recorder's zero, it could be interpreted as either zero drift or a positive concentration. In calculating averages we assumed the latter, possibly biasing the results particularly if the average was below 0.001 to 0.005 mg/m^3. Time constants could be selected as 0.5, 2, 8, or 32 s, the latter being used most often. The long time constant significantly dampened out noise in the trace and sensitivity to a rapid concentration fluctuation.

During the testing, several blank filters were submitted to observe the precision of methods and the background content of uranium. These filters were handled in the same fashion as exposed filters including their installation in filter holders and handling in the field. At least one such blank was handled during rounds 4 to 10.

3.0 DATA ANALYSIS

3.1 DATA BASE

Data from routine monitoring and additional temporary air-sampling equipment were collected for 10 rounds fired at Ford's Farm during February 1980. The samplers used are summarized in Table 3.1. Data from the air samplings are listed in Appendix A.

The basic data of Appendix A create several problems in answering the questions of interest. First, many data values are missing (indicated by dashes in Appendix A, Tables A.2, A.4, and A.5), particularly for the first three rounds. Of the 41 missing values, 25 are in the first three rounds. Second, there are 12 values reported as "less than," indicating a detection limit value. These are preceded by a minus sign in Appendix A, Tables A.1 and A.5. Third, inlet and workplace total and respirable samples filters were not renewed between rounds 3 and 4 and 5 and 6. Thus, only two analytical results for each of these samplers represent the concentrations for four rounds. These problems in the data base make routine analysis difficult to interpret. For example, a correlation coefficient between AC.C and the workplace cyclone would be based on only two, not ten valid data pairs.

3.2 COMPARISON OF EXPOSED FILTER CONCENTRATIONS AND BLANK VALUES

A single field blank (unexposed filter) was submitted to the analytical lab with the filters for each of rounds 4 through 10. The resulting data are given in Table 3.2.

The average and standard deviation of the total activity of the blank filters were calculated to check the consistency of the blanks. It would be expected that uncontaminated blanks should produce results in fairly close agreement, even when analyzed over a period of weeks. The standard deviation relative to the mean is 180%, indicating considerable lack of agreement. The range of activities, 0.06 to 16.00 pCi, with an intervening detection limit value of <0.24 pCi, also demonstrates a lack of consistency. The standard deviation is large enough that the average, 3.19 pCi/m^3, could not be judged

TABLE 3.1. Sampler Identification

Routine	Sampler Name	Sampler Type	Sampler Location	Medium Sampled	Analytical Units
1.	EXH.M	RAM-1	Exhaust duct	Total particulates	mg/m^3 dust
2.	EXH.L&R	Filters	Exhaust duct	Total particulates	aCi/ml DU
3.	INLET	RAM-1	Before exhaust grill	Respirable particulates	mg/m^3 dust
3a.	SEQ.A-E	RAM-1	Before exhaust grill	Respirable particulates	Average mg/m^3
4.	RDM	RDM-301	Cart near door	Respirable particulates	mg/m^3 dust
5.	TSI	TSI-3500	Workplace traverse	Respirable particulates	mg/m^3 dust
Temporary					
6.	INFILT	Filters	Before exhaust grill	Total particulates	aCi/ml DU
7.	INCYCL	Filters with cyclone	Before exhaust grill	Respirable particulates	aCi/ml DU
8.	WKFILT	Filters	Near door	total particulates	aCi/ml DU
9.	WKCYCL	Filters with cyclone	Near door	Respirable particulates	aCi/ml DU
10.	SEQ.A-E	Filters	Before exhaust grill	Total particulates	fCi/ml DU
Other Measurements					
11.	Field blanks	Filters	---	Unexposed filters	pCi DU per filter
12.	All	Flow meter	---	Air flow rate	m^3/min
13.	All	Clock	---	Time of filter exposure	min

TABLE 3.2. Field Blank Filter Analyses

Round	pCi DU/ Filter	Two Standard Deviations[a]
4	1.20	0.80
5	0.35	0.31
6	3.20	1.30
7	<0.24	--
8	1.30	1.00
9	0.06	0.04
10	16.00	3.00
Mean	3.1829	
Standard Deviation	5.7474	

(a) According to counting statistics.

statistically different from zero. The conclusion is that an average blank correction could not be used. The data for each round should be corrected for its accompanying blank.

The blank correction is complicated since the total activities in Ci per blank filter need to be converted to concentrations, in effective Ci/l. This was done by dividing the pCi per blank filter by the volume of air sampled. Let

X_{ij} be the Ci/ml for sampler i and round j
V_{ij} be the corresponding volume, m^3, of air sampled
b_j be the pCi for the blank filter associated with round j.

Then the blank correction was calculated as

$$b'_{ij} = (b_j \times 10^{-12} \text{ Ci})/[V_{ij} \times 10^6] \text{ ml/m}^3 = (b_j/V_{ij}) \times 10^{-18}$$

and the blank corrected concentration was

$$X'_{ij} = X_{ij} - b'_{ij}$$

The large blank corrections for round 10 caused 4 of the 11 samples to go negative, and 2 of the round 6 values were swamped by their blanks. These considerations lead to the somewhat subjective conclusion that all but the round 10 blank value (16 pCi) are reasonable. It was decided to blank correct all of the filter data, using the blank filter results for rounds 4 through 9. The average of the blanks for rounds 4 through 9, (1.0583 pCi) was used to correct the data for rounds 1, 2, 3, and 10. Another operating decision was to treat the "less than" values as actual concentrations.

The results of these calculations are given in Appendix B. The X'_{ij} block of data (Table B.4) are the blank adjusted data to be used in subsequent calculations. The ten negative values are the values for which the blank correction was greater than the exposed filter concentration. Seven of these negative values are for the cyclone samples. The nine parenthesized values are the adjusted values for the "less than" detection limit concentrations.

Appendix B, Table B.5, also has the background as a percentage of the unadjusted Ci/ml data; i.e.,

$$P_{ij} = 100 \frac{b'_{ij}}{X_{ij}} .$$

The percentage background is followed by the grams of DU per cubic meter of air, in Table B.6, calculated by

$$U_{ij} = (X'_{ij}/0.36)$$

which results in mg/m^3 for the sequential samplers and micrograms (μg/m^3) for the other filter samples. This calculation puts the temporary samplers into the same units as the routine samplers. Finally, the natural logarithms of these data are given in Table B.7.

3.3 COMPARISON OF EXHAUST RAM-1 AND EXHAUST FILTERS

The exhaust RAM-1 measured the total dust particulates in mg/m^3 air. The exhaust filters (right and left sides of the exhaust stream) were analyzed for attocuries due to DU per milliliter of air ($Ci \times 10^{-18}/ml$). The DU activity was corrected for blanks (as explained previously) and transformed to micrograms of DU per cubic meter of air sampled ($\mu g\ DU/m^3$), using 3.6×10^{-7} Ci/g of DU. The resulting data are given in Table 3.3, where $\overline{EXHF}$ is the average of the left and right exhaust filters. The negative value for EXHL in round 6 is due to a large blank.

The main interest in this comparison is to determine how the uranium concentration measured for the filters relates to the total dust-particulate concentration measured by the RAM-1. The stated criterion for exhaust air is 3.0×10^{-12} $\mu Ci/ml$, or 8.33 $\mu g\ DU/m^3$. The average for the filters is 2.368 $\mu g\ DU/m^3$; for the RAM-1 it is 1.880 $\mu g\ dust/m^3$. The average filter $\mu g\ DU/m^3$ is 28% of the criterion value and the RAM-1 dust is 23% of the criterion. None of the observed concentrations are as great as the criterion.

The fact that the average DU concentration (2.368 $\mu g/m^3$) is typically greater than the dust concentration (1.880 $\mu g/m^3$) goes against the logic of the part being less than the whole. The column of differences in Table 3.3 shows that the EXH.M (dust particles) result was greater than the $\overline{EXHF}$ DU concentration only for round 3 and the three rounds with EXH.M at its detection limit value. When the five 1.0 $\mu g/m^3$ EXH.M values are removed, the average difference is 1.11 $\mu g/m^3$. This difference is significantly different from zero, using a t-test at the 90% critical value. These results indicate some relative bias in the sampling DU-concentration analysis. The problem is most likely with the RAM-1 calibration because of zero drift and the technique used in calculating the EXH.M average value from the strip chart.

Despite these anomalies in the data, a linear regression was done to see if a relationship existed between the dust and DU data. The results are summarized in Figure 3.1. When all 10 rounds were used, the correlation between EXH.M and $\overline{EXHF}$ was a respectable 0.83, and there was a linear relationship. However this relationship depended on "anchoring" by the five 1.0 values.

TABLE 3.3. Data for Comparison of Exhaust RAM-1 and Exhaust Filters, μg/m^3

Round	EXH.L	EXH.R	$\overline{EXHF}$	EXH.M	$\overline{EXHF}$-EXH.M
1	4.69	6.63	5.660	2.40	3.260
2	0.86	0.659	1.00	1.00	-0.341
3	1.11	1.55	1.329	2.00	-0.671
4	3.52	4.35	3.936	3.50	0.436
5	3.78	4.06	3.922	3.00	0.922
6	-0.54	0.91	0.185	1.00[a]	-0.815
7	0.72	0.94	0.827	1.00[a]	-0.713
8	2.57	1.35	1.963	1.00	0.963
9	0.56	0.79	0.674	1.00[a]	-0.326
10	4.38	4.66	4.521	2.90	1.621
Average	2.166	2.570	2.368	1.880	0.488
Standard Deviation	1.85	2.16	1.96	1.00	1.2566

(a) These values were reported as <1.0, indicating detection limit values.

The steeper line shows the best least-squares linear fit to all the data. When the five 1.0 EXH.M values were removed, the correlation dropped to 0.39 and the relationship was not different from assigning the average EXH.M value, 2.76 μCi/m^3, for any $\overline{EXHF}$ value. The dashed lines show the intersection of the average values for each data set.

The data do not support the expected relationship between the exhaust monitor total dust particulates and the filter DU concentrations. An explanation is that at this low end of the RAM-1's range the readings are below the manufacturer's claimed precision (5 μg/m^3) and stability. The test result does not invalidate the usefulness of the RAM-1 in detecting an abnormally high concentration caused by filter bank leakage or extremely high concentration upstream of the filters. The RAM-1 should not be used to estimate weekly averages below 5 μg/m^3.

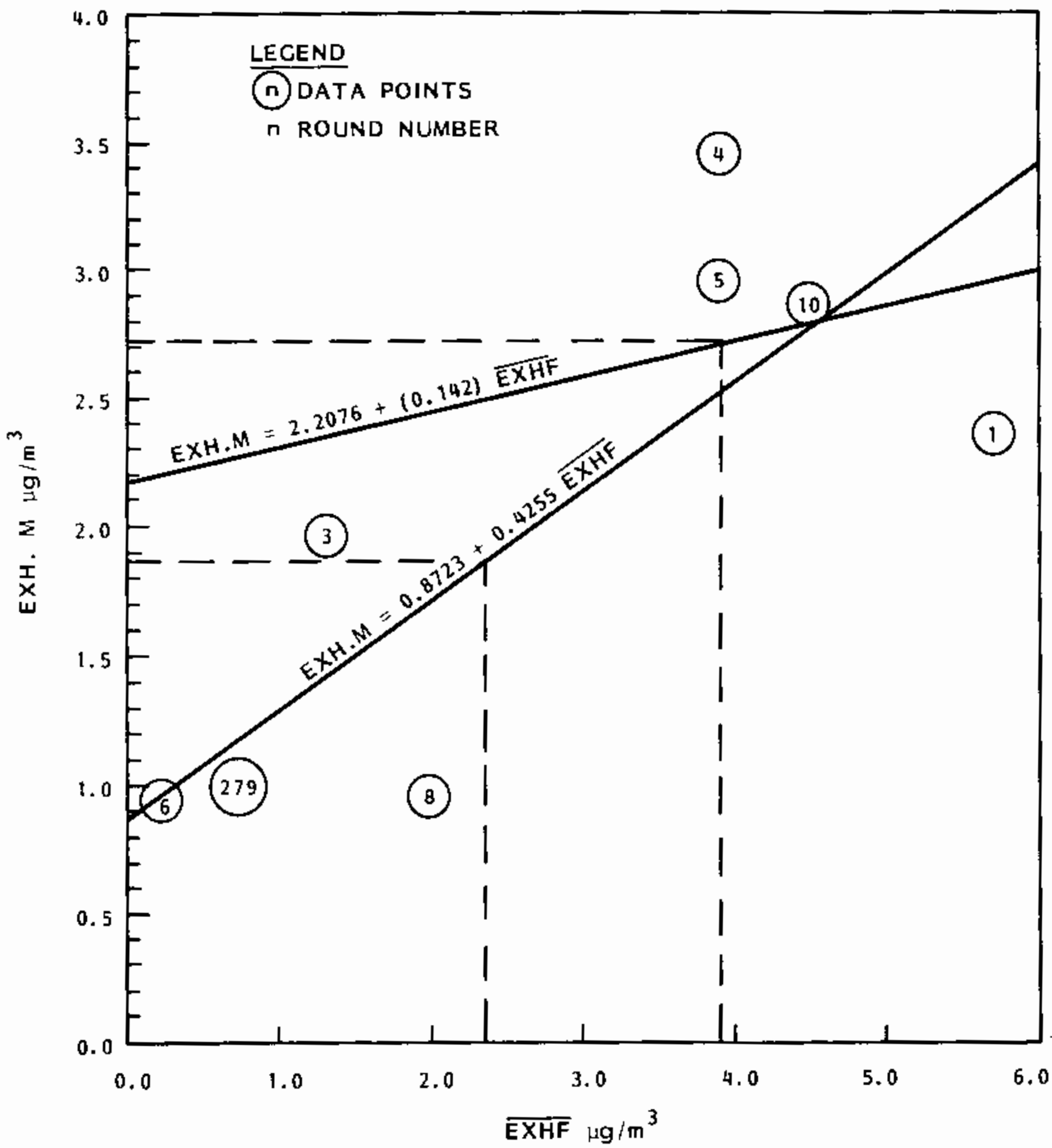

FIGURE 3.1. Relationships Between Total Particulates (EXH.M) and Airborne DU (EXHF) in the Exhaust Stream

3.4 RAM-1 MONITOR RESPONSES

The experiment was not properly designed to test the functioning of the monitor under conditions of abnormal release where the concentrations present are beginning to be in the useful range of the instrument. An example of the exhaust monitor's response is shown in Figure 3.2. Exhaust air samples with the same duration as the release would probably allow assessing the accuracy of the monitor's response in these situations.

Some of the inlet and exhaust RAM-1 responses are summarized by round in Table 3.4. The clearance time is the interval between the shot and dust clearance to a concentration of 0.05 mg/m^3 for the inlet RAM-1. The exhaust alarm duration is the interval over which the exhaust monitor's reading exceeded 0.008 mg/m^3. Of interest to the ventilation filter performance is the

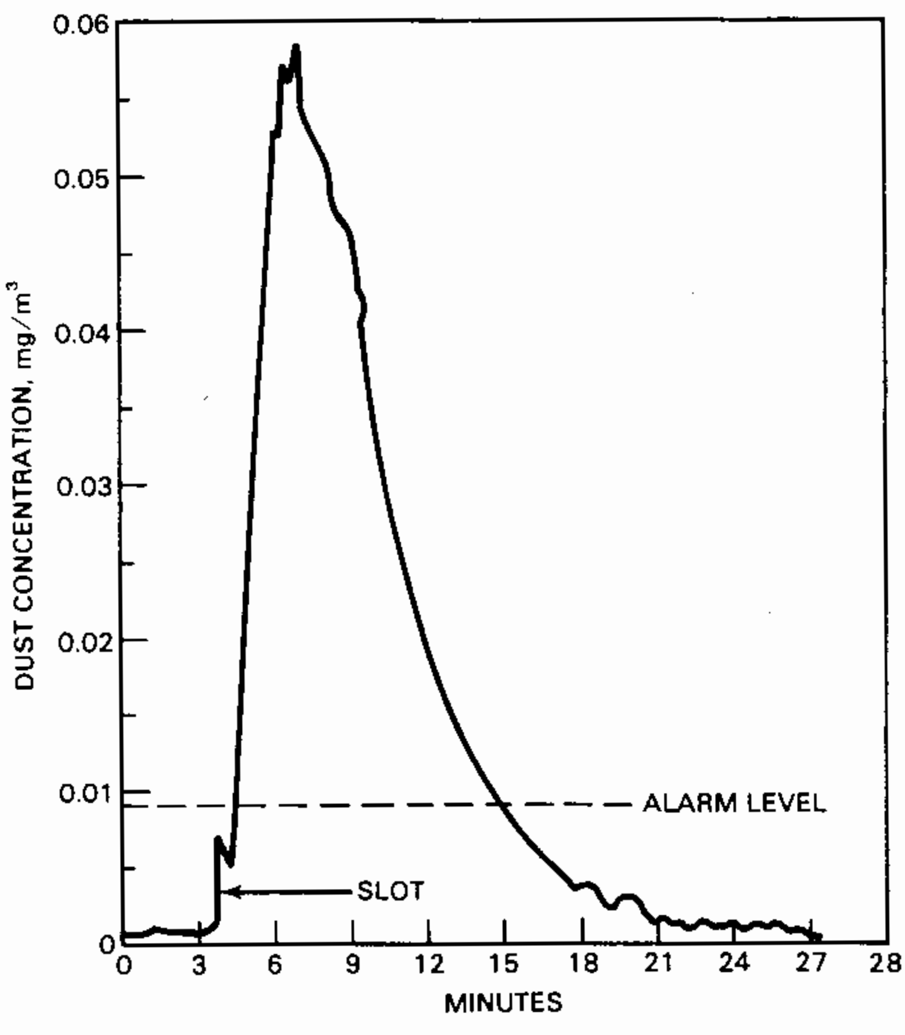

FIGURE 3.2. Round 10 Exhaust Monitor Trace

TABLE 3.4. Monitor Responses

Round	Exhaust Alarm Duration (min)	Exhaust 20-min Average (mg/m^3)	Exhaust Peak (mg/m^3)	Inlet Peak[a] After Purge (mg/m^3)	Inlet Clearance Time (min)
1	8.4	0.0082	0.021	OS	22
2	0.5	0.0024	0.028	OS	17
3	4.2	0.0109	0.115	OS	19
4	12.0	0.0132	0.028	OS	33
5	15.0	0.0161	0.038	182	66
6	none	D.0013	0.006	12	23
7	none	0.D010	0.005	55	20
8	none	0.0030	0.008	53	35
9	none	D.0010	0.004	62	17
10	11.4	0.0182	0.059	92	32
Average	5.2	0.0075	0.031	76	28

(a) OS means concentration was off scale of the RAM-1.

exhaust monitor average and peak reading during the first 20 min after each shot. The peak reading of the inlet monitor after purging is listed for cases when the reading was not off-scale. The averages of the data are also given.

A typical exhaust monitor readout is shown in Figure 3.2. The exhaust monitor traces for 9 out of 10 rounds exhibited a leading peak followed by a more gradual release either higher or lower than the leading peak. The leading peak is believed to be the release resulting from the pressure wave passing through the exhaust system. The dust released at that time is either from the round's impact or resuspension from the ductwork or filter media. The remainder of the release occurs during normal airflow and is probably due to filter leakage or the very high concentration upstream of the filters.

3.5 COMPARISON OF ANALYTICAL METHODS FOR EXHAUST FILTER SAMPLES

The exhaust air stream was sampled by a pair of filters for each round, one in the right and one in the left sector of the exhaust duct. The total uranium was determined by fluorimetry, alpha counts, and beta-gamma counts in microcuries x 10^{-12}/ml. Since alpha and beta-gamma counts are less accurate (precision and bias sense), but cheaper than fluorimetry, it is of interest to determine any relationship between the analytical methods.

The data, ordered by the rank of the average of the right and left uranium values, and the averages and standard deviation (sd) are given in Table 3.5. Despite high concentrations based on the counting data, the round 3 uranium (fluorimetry) values were at the detection limits (0.52 and 0.68); the reverse situation was observed for round 4. The effect of these anomalies is shown in Figure 3.3. When two or more analytical results are separated by less than the plotting interval (about 0.15 x 10^{-12} μCi/ml for Figure 3.3), the number of coinciding points is plotted. Note also, in Table 3.5, that both the alpha and beta-gamma counts are low relative to the fluorimetry result for round 1, the round with the largest average fluorimetry uranium value. Rounds 3 and 4 will be removed from the following analyses and results for all three data sets will be reported.

It is obvious in Figure 3.3 that the alpha and beta counts tend to increase with average uranium. (When two or more points coincide, the number of coincident points is used as the plotting symbol.) The averages without rounds 3 and 4 show that results on the left side were slightly greater than those on the right side. However, the differences of 0.1 to 0.2 x 10^{-12} μCi/ml were not statistically significant. Correlations between the left- and right-side results for each analytical method are given in Table 3.6. Removal of round 3 significantly improved the alpha correlation by removing the (3.170, 0.458) point. Removal of round 4 caused the beta correlation to drop because the identical detection limit values [(2.2, 2.2), the largest beta values after the removal of round 3] were removed. Analysis of variance and individual regression on these data confirmed that it would be reasonable in subsequent analysis to use the average of the right and left data for each method. These averages are plotted in Figure 3.4. The averages for rounds 3 and 4 are joined by a vertical line. Table 3.7 has the results for the analysis of the averages.

The correlations show that removal of round 3 improved the relationship between U and alpha and U and beta counts. Subsequent removal of round 4

TABLE 3.5. Exhaust Filter Data, μCi/ml x 10^{-12}

Round	Average Uranium	Right			Left			Rank EXH.M Concentration	Rank INLET + TSI Concentration
		U	α	β	U	α	β		
9	0.25	0.210	0.118	<0.100	0.290	0.362	0.241	3	6
7	0.33	0.290	<0.030	0.162	0.370	0.508	0.309	3	4
2	0.34	0.413	0.561	0.088	0.267	0.317	<0.090	3	9
6	0.45	0.190	0.256	0.128	0.710	0.731	0.556	3	2
(3)	0.60	<0.52	3.170	2.720	<0.68	0.458	2.530	6	1
8	0.88	1.10	1.020	0.795	0.66	0.823	0.535	3	7
5	1.45	1.40	1.830	1.170	1.50	1.75	1.200	9	8
(4)	1.65	1.50	<0.810	<2.200	1.80	<0.81	<2.200	10	10
10	1.75	1.70	1.610	0.923	1.80	1.91	1.040	8	3
1	2.25	1.90	1.000	1.010	2.60	1.89	1.670	7	6
Average	0.9950	0.9223	1.0405	0.8286	1.0677	0.9559	1.0371		
sd	0.721	0.668	0.958	0.915	0.802	0.642	0.853		
	Without Round 3								
Average	1.0389	0.9670	0.8039	0.7307	1.1108	1.0112	0.8712		
sd	0.750	0.693	0.634	0.704	0.838	0.655	0.714		
	Without Rounds 3 and 4								
Average	0.9625	0.9004	0.8031	0.5470	1.0246	1.0364	0.7051		
sd	0.763	0.709	0.678	0.469	0.852	0.896	0.546		

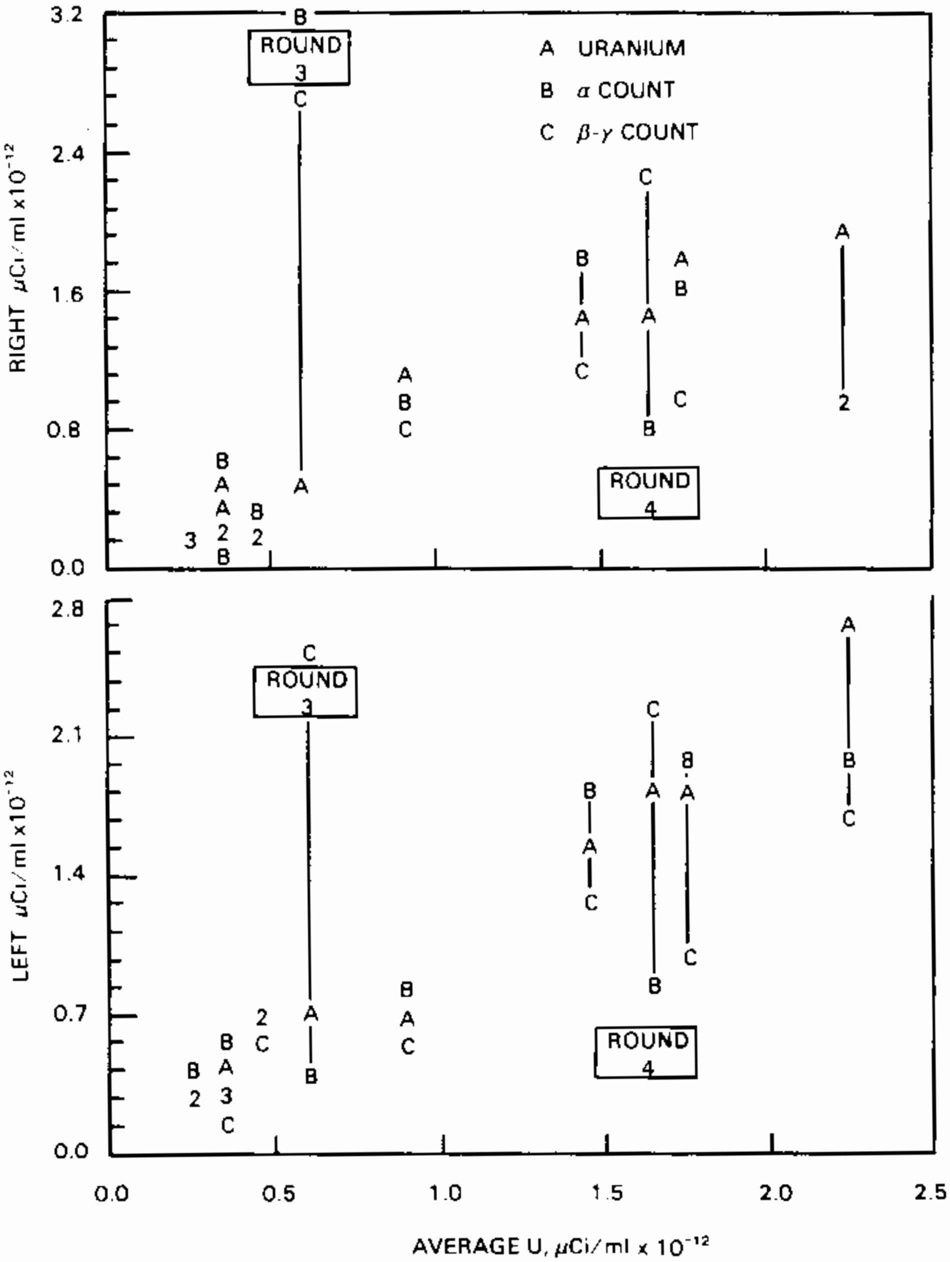

FIGURE 3.3. Exhaust Filter Data

TABLE 3.6. Correlations Between Left and Right Results

Method	All	Removed Round 3	Removed Rounds 3 and 4
Fluorimetry	0.922	0.920	0.912
Alpha	0.288	0.833	0.839
Beta-Gamma	0.955	0.930	0.860

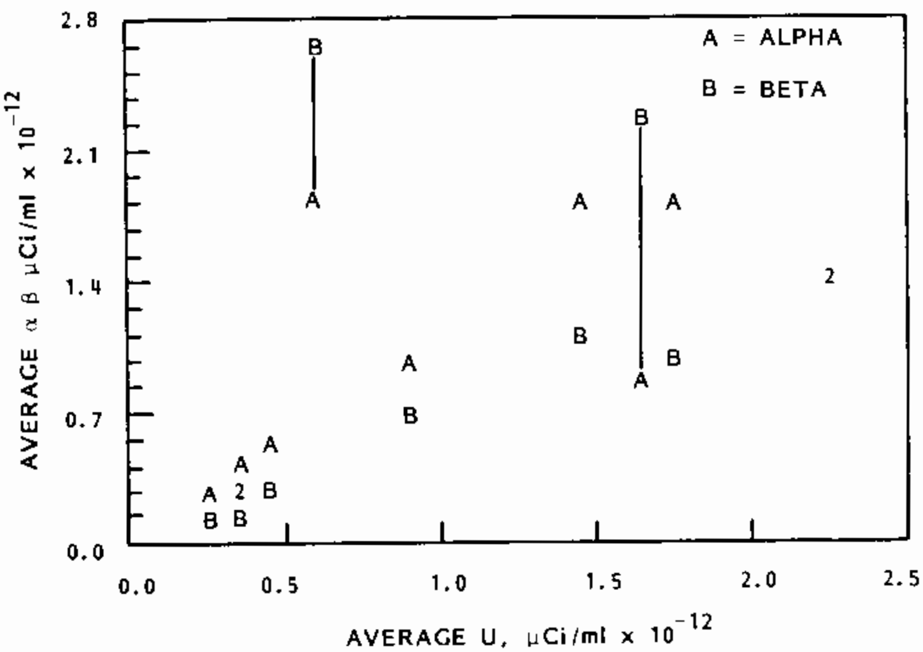

FIGURE 3.4 Alpha and Beta Counts Versus Average Uranium

improved the relationship between alpha and beta counts. The resulting least-squares fits of the counting averages to the uranium average is shown in Figure 3.5. The round numbers for the (alpha, uranium) points are also plotted. If the counting and fluorimetry results were the same ($\alpha = \beta = U$) then the intercept, a, in

$$\alpha = a + bU$$

would be zero and the slope, b, would be unity. The results for rounds 3 and 4 removed, in Table 3.7, show that the intercepts are not different from zero. When the intercept is forced through zero, the slope for the alpha data changes from 0.7783 to 0.8926, which is not statistically different from unity. But, for the beta data, the slope changes from 0.6176 to 0.6388, both of which are significantly less than unity. The final result is that the alpha-counting results are slightly less than the fluorimetry and the beta results significantly underestimate the fluometry values.

TABLE 3.7. Summary of Least-Squares Regressions for Exhaust Filter Analytical Methods

		Removed		
Statistic	All	Round 3	Rounds 3 & 4	Rounds 3 & 4
Correlations				Intercept
$r(U, \alpha)$	0.654	0.839	0.902	Set = 0.0
$r(U, \beta)$	0.487	0.833	0.963	
$r(\alpha, \beta)$	0.674	0.567	0.931	
Regressions				
$\alpha = a + bU$				$\alpha = bU$
Intercept	0.4126	(0.1899)[a]	(0.1706)[a]	0.0
Slope	0.4884	0.6907	0.7783	0.8926
sd (slope)	0.241	0.169	0.152	0.0898
sd (resid)	0.5206	0.3587	0.3070	0.3040
R^2	42.7	70.4	81.4	
R^2 (adj)	35.6	66.2	78.3	
$\beta = a + bU$				$\beta = bU$
Intercept	0.3954	(-0.0028)[a]	(0.0316)[a]	0.0
Slope	0.5908	0.7736	0.6176	0.6388
sd (slope)	0.374	0.194	0.071	0.0395
sd (resid)	0.8096	0.4118	0.1431	0.1340
R^2, %	23.7	69.4	92.7	
R^2 (adj)	14.2	65.0	91.5	

Fitted Values	α	β	α	β	α	β	α	β
U = 0.0	0.41	0.40	0.19	-0.00	0.17	0.03	0.0	0.0
U = 1.0	1.00	0.99	0.88	0.77	0.95	0.65	0.98	0.64
U = 2.5	1.88	1.87	1.92	1.93	2.12	1.48	2.23	1.60

(a) Parenthesized values are not statistically different from zero.

[CAUTION: These results, based on questionable 2-yr old data, should not be used for adjusting alpha or beta counts for the apparent bias relative to fluorimetry results.]

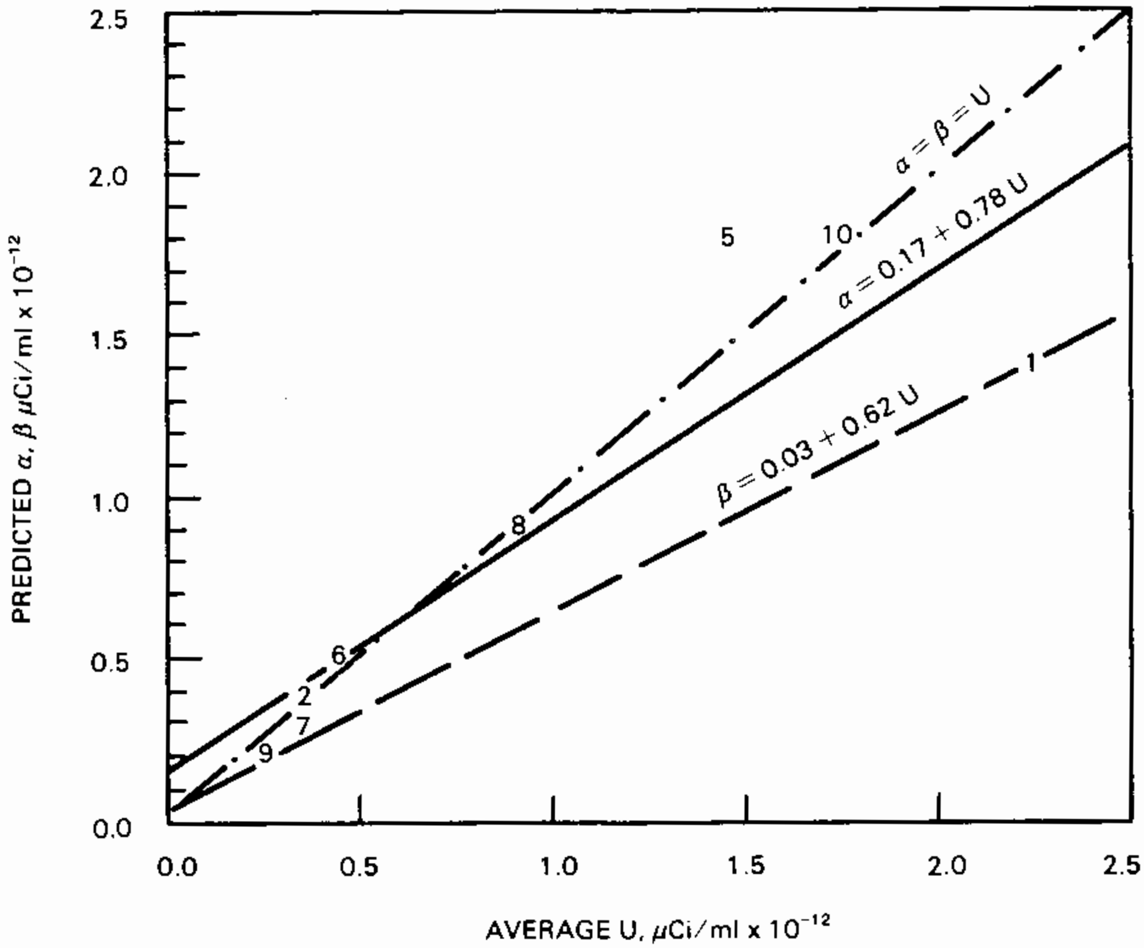

FIGURE 3.5. Least-Squares Fits of Counting Results to Fluorimetry Results

3.6 COMPARISON OF INLET RAM-1 WITH INLET AND WORKPLACE FILTER RESULTS

After workers are allowed in the building, the Inlet RAM-1 monitors the dust concentration in lieu of a radiation-monitoring device. The MPC is 0.2 mg/m^3 of DU, (7.0×10^{-11} μCi/ml) for occupational exposure. The Ford's Farm study used four filter samplers to measure the uranium concentration related to the RAM-1: open-faced filters near the RAM-1 and the workplace entrance (INLET and WKFILT), and respirable cut (3.5 microns AEO cyclone) filters near the open-faced filters (INCYC and WKCYC).

The data are given in Table 3.8 in μg/m^3. Six of the ten workplace cyclone samples gave results below analytical detection limits (d in Table 3.8)

TABLE 3.8. Data for Inlet RAM-1 Comparison with Inlet and Workplace Filters, μg/m^3

Round	INLET	INFILT	INCYC	WKFILT[a]	WKCYC[a]
1	30	-1.1150	-0.5023	0.3914d	6.858
2	45	6.7179	-0.1495	3.5434	46.905d
3	17	18.1670	1.8332	10.4127	-3.048d
4	140	18.0590	1.7612	10.3003	-5.787d
5	34	68.0587	1.7204	49.4024	61.620
6	15	65.8223	0.2124	46.7982	-4.352
7	17	2.3170	1.4259	0.6545	71.839
8	25	72.6243	21.4506	42.0687	-58.407d
9	20	6.5570	2.4616	2.1681	33.333d
10	19	21.6555	-0.0118	54.6861	139.179

(a) "d" indicates the value was based on "less than detection limit" result reported by the lab.

and/or were made negative by the blanks. Other anomalies in the data are: the 140-μg/m^3 value for the Inlet RAM-1 for round 4 and the 21.45-μg/m^3 values for the INCYC on round 7.

The correlations of the filter data with the Inlet RAM-1 are not statistically different from zero and are all negative: -0.130 with INFILT, -0.075 with INCYC, -0.213 with WKFILT, and -0.209 with WKCYC. Removing round 4 data only brings the correlations closer to zero. The highest correlation among all the variables is 0.818 (0.816 without round 4) between the WKFILT and INFILT data. The next highest is 0.540 (0.537) between the INFILT and INCYC data. The WKCYC and INCYC data have a negative correlation -0.578 (-0.609). None of the other correlations are above 0.3 in absolute value. A correlation coefficient of at least 0.549 is necessary to judge the correlation coefficient to be greater than zero, allowing a 1 in 20 chance of being wrong.

The data do not support a linear relationship between the Inlet RAM-1 and the filter results. The problem is evident in Figure 3.6, which plots the INFILT and WKFILT data against the Inlet RAM-1 data with round 4 removed. Any

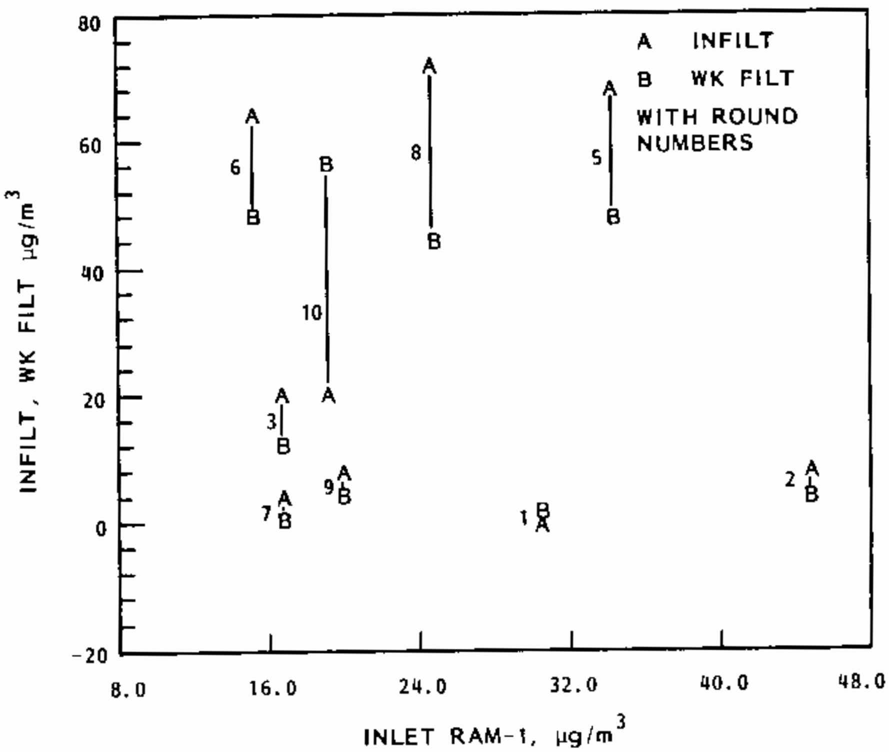

FIGURE 3.6. Comparison of Inlet RAM-1 and Inlet and Workplace Filter Data

attempt at fitting a straight line is doomed by the high-filter data for round 6 or the low-filter data for rounds 1 and 2.

3.7 COMPARISON OF SEQUENTIAL RAM-1 AND FILTER RESULTS

The continuous readout from the Inlet RAM-1 was averaged over time periods corresponding to the sequential open-faced filter sampler's periods of exposure. The questions of interest expected to be answered by these data were:

- Does the concentration decrease at the same rate for both types of samples?
- Can the sequential filters and RAM-1 results provide a relationship for setting a RAM-1 (dust) concentration corresponding to the MPC for uranium measured by the sequential filters?

The pairs of data are listed in Table 3.9. The sequential filters were not operable for rounds 1 and 8; these rounds are not listed. The only data listed for the remaining rounds are those for which both the RAM-1, R, and sequential filters, F, had results. These data were transformed by taking their natural logarithms given in Table 3.10. Except for round 5, this transformation tended to linearize the relationship over time periods. Typically, sequences A, B, and C were 5 min long; sequence D varied from 2 to 16 min; and sequence E from 15 to 60 min. Figure 3.7 shows the duration of the sampling times for each round. Figure 3.8 gives plots of the logarithmic data against the time midpoints for the sampling periods. Round 5 had the highest concentration at each period, about twice as large as round 10 at sequence B, and more than four times as large at sequence E. (Round 5 had missing data for sequence C.) The sequence C filter for round 10 declined only slightly from

TABLE 3.9. Sequential RAM-1 and Filter Data, mg/m^3

Round		Sequence				
		A	B	C	D	E
2	Ram-1	---	0.022	---	---	---
	Filter	---	0.007	---	---	---
3	R	---	0.017	---	---	---
	F	---	0.012	---	---	---
4	R	---	---	13.100	---	---
	F	---	---	9.419	---	---
5	R	---	77.000	---	22.000	2.700
	F	---	91.659	---	30.537	4.999
6	R	---	5.699	---	0.260	0.032
	F	---	19.639	---	0.181	-0.003
7	R	---	9.100	1.049	0.055	0.017
	F	---	12.217	1.633	0.037	0.002
9	R	37.000	4.199	0.380	0.059	0.020
	F	69.443	4.998	0.637	0.132	0.006
10	R	---	34.000	6.000	0.170	0.024
	F	---	49.978	42.211	2.114	0.801

TABLE 3.10. Sequential RAM-1 and Filter Data, $\log_e$ (mg/m^3)

Round		Sequence A	B	C	D	E
2	R	---	-3.8167	---	---	---
	F	---	-4.9257	---	---	---
3	R	---	-4.0745	---	---	---
	F	---	-4.3848	---	---	---
4	R	---	---	2.5726	---	---
	F	---	---	2.2428	---	---
5	R	---	4.3438	---	3.0910	0.9932
	F	---	4.5180	---	3.4189	1.6093
6	R	---	1.7404	---	-1.3470	-3.4420
	F	---	2.9775	---	-1.7079	---
7	R	---	2.2082	0.0487	-2.9004	-4.0745
	F	---	2.5028	0.4910	-3.2875	-5.8751
9	R	3.6109	1.4350	-0.9675	-2.8134	-3.9120
	F	4.2405	1.6091	-0.4504	-2.0226	-5.0724
10	R	---	3.5263	1.7917	-1.7719	-3.7297
	F	---	3.9115	3.7426	0.7490	-0.2217

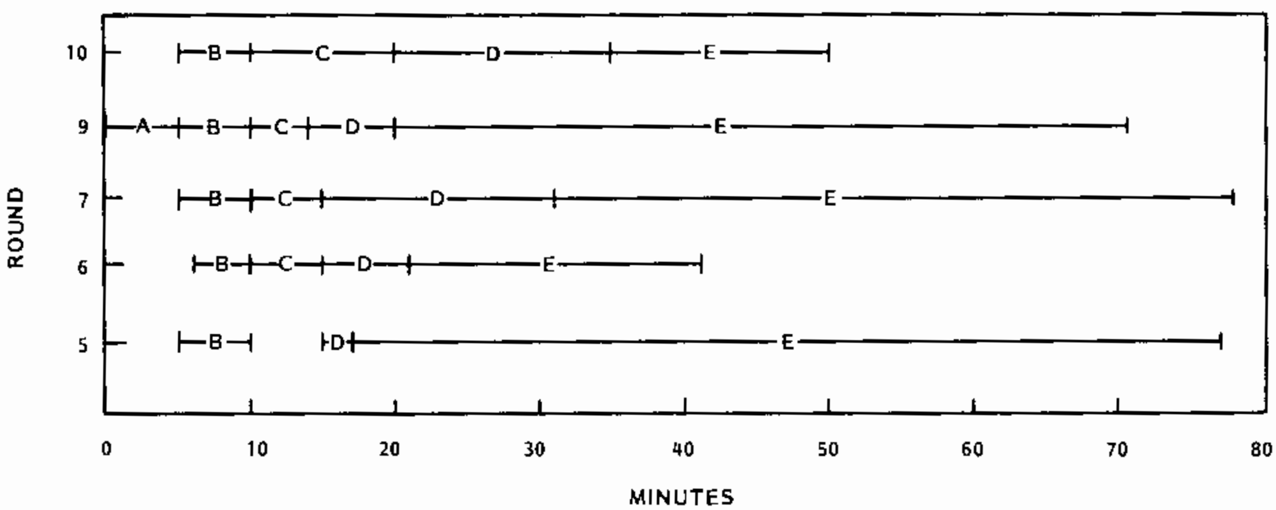

FIGURE 3.7. Sequential Sample Duration for Rounds 5 to 7, 9 and 10

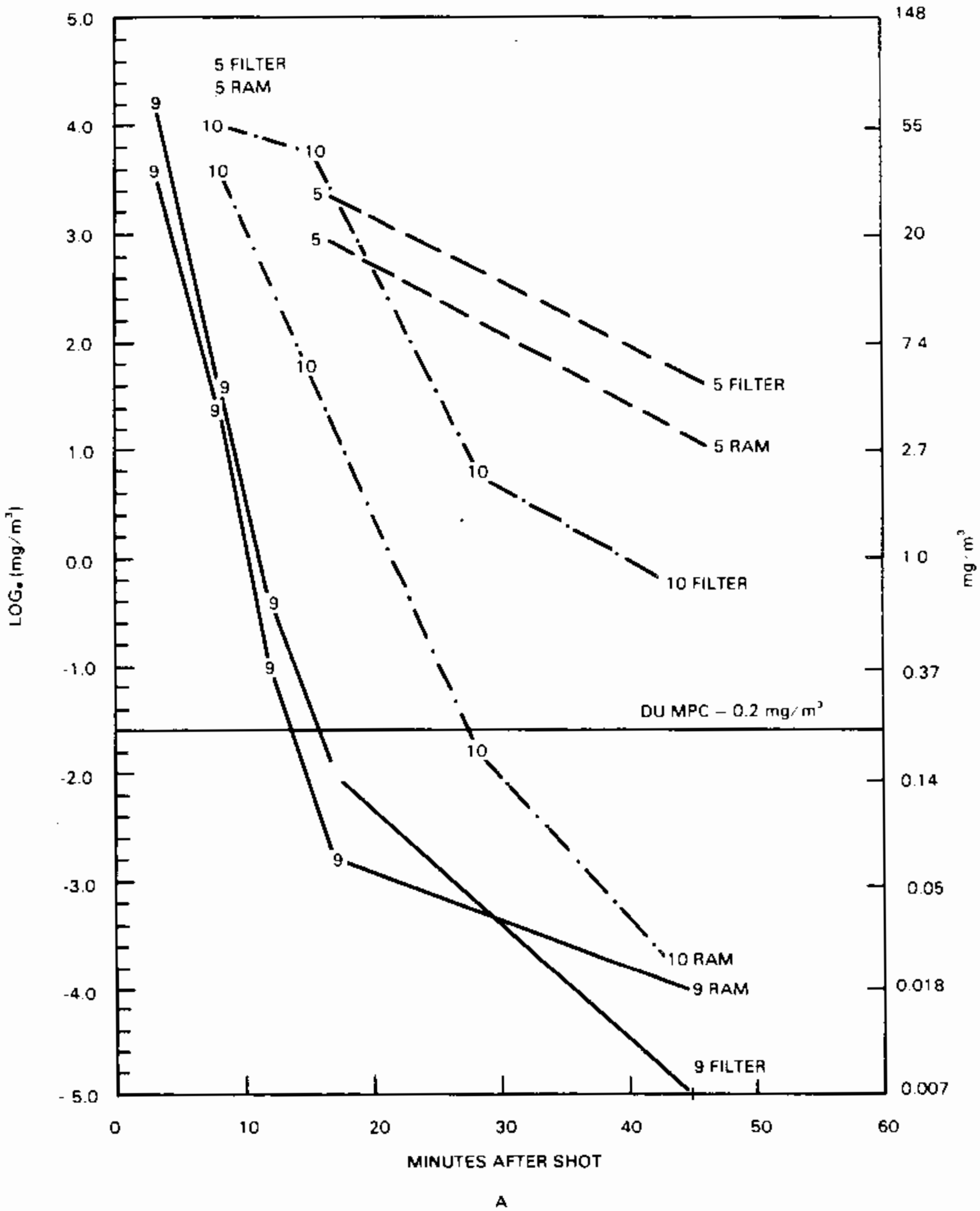

FIGURE 3.8. Concentrations for RAM-1 and Sequential Filters Versus Sampling Period Time Midpoint, with Round Numbers: (a) Rounds 5, 9, and 10.

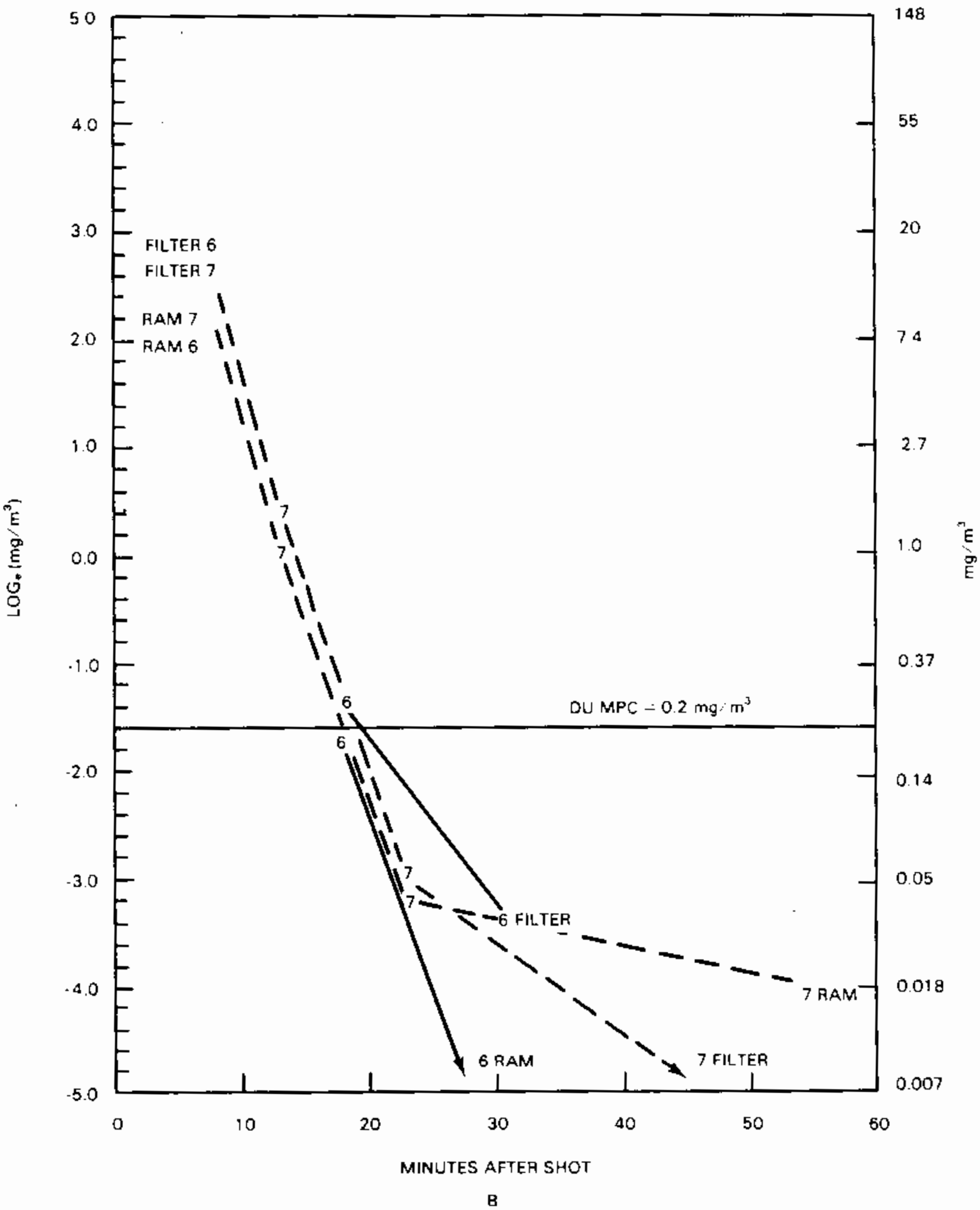

FIGURE 3.8 (contd). Concentrations for RAM-1 and Sequential Filters Versus Sampling Period Time Midpoint, with Round Numbers: (b) Rounds 6, 7.

sequence B (from 59.978 to 42.211 mg/m^3). For round 6, the sequence E point was negative due to the blank correction and was treated as missing on the logarithmic scale. Rounds 2, 3, and 4 had only one data pair and are not included in the plot.

The differences in duration of sampling for the same sequence complicates the interpretation of the results. The sequence A sampling commenced almost simultaneously with the round's striking the target, and most RAM-1 readings were off-scale. Since particulate concentration is depleted rapidly from various initial concentrations (4 to 95 mg/m^3 for rounds 5 through 10 for sequence B), comparison of rates of depletion from round to round may depend on the time the sampler was turned on after the shot or when averaging started. The rates of depletion on the logarithmic scale over the first four sampling periods appear to be linear, except for the round 10 filter, sequence C, as shown by Figure 3.8. Except for round 10, the RAM-1 and filter results compare closely on both depletion rate and concentration level, at least through sequence D. As with the inlet and workplace filters, the RAM-1 results are lower than the filter results except for sequence E of rounds 7 and 9.

The rate of decline was calculated as:

$$DT_{si,j+1} = (x_{sij} - x_{sij,j+1})/t_{i,j+1}$$

where:

$DT_{si,j+1}$ is the rate of decline per minute over period j + 1 in Round i, for the sampler Type s

x_{sij} is the mg/m^3 for s_{ij}

$t_{i,j+1}$ is the duration of sampling,

and subscripts

s = 1 for RAM-1, or 2 for filters,

i = 5, 6, 7, 9, 10, the round number,

j = B, C, D, E for sampling sequence.

The results of this calculation are given in Table 3.11. The correlation coefficient between RAM-1 (R) and Sequential Filter (F) data in the cells of

TABLE 3.11. Ouration of Sampling and Rates of Depletion for RAM-1 and Sequential Filters, (mg/m^3) Minutes

Round	Data	Sequence B	Sequence C	Sequence 0	Sequence E
5(E)	t	5.000	---	2.000	60.000
	R	---	---	27.500	0.321
	F	---	---	30.560	0.425
6(F)	t	4.000	---	6.000	20.000
	R	---	---	0.906	0.011
	F	---	---	3.243	0.009
7(G)	t	5.000	5.000	16.000	47.000
	R	---	1.610	0.062	0.000
	F	---	2.116	0.099	0.000
9(I)	t	5.000	4.000	6.000	50.700
	R	6.559	0.995	0.053	0.000
	F	12.888	1.090	0.084	0.002
10(J)	t	5.000	10.000	15.000	15.000
	R	---	2.799	0.388	0.009
	F	---	0.776	2.673	0.087

t = sampling duration, min.
R = rate of concentration decline for Inlet RAM-1 (0T on p. 3B), (mg/m^3)/min.
F = rate of concentration decline for sequential filters (DT on p. 38), (mg/m^3)/min.

Table 3.11 is 0.977, indicating good agreement of the depletion rates for each cell. A scatterplot of the depletion rates in Figure 3.9 is on the natural log scale so that low rates can be distinguished. As might be expected from previous results, the points for round 10 deviate most from the line indicating equality of depletion rates.

The conclusion is that depletion rates are nearly the same for the same sequences and round, but change from round to round and sequence to sequence.

A least-squares fit (regression) of the filter to the RAM-1 sequential data on the logarithmic scale resulted in the linear relationship:

$$\log_e (F) = 0.095 + 1.127 \log_e (R)$$

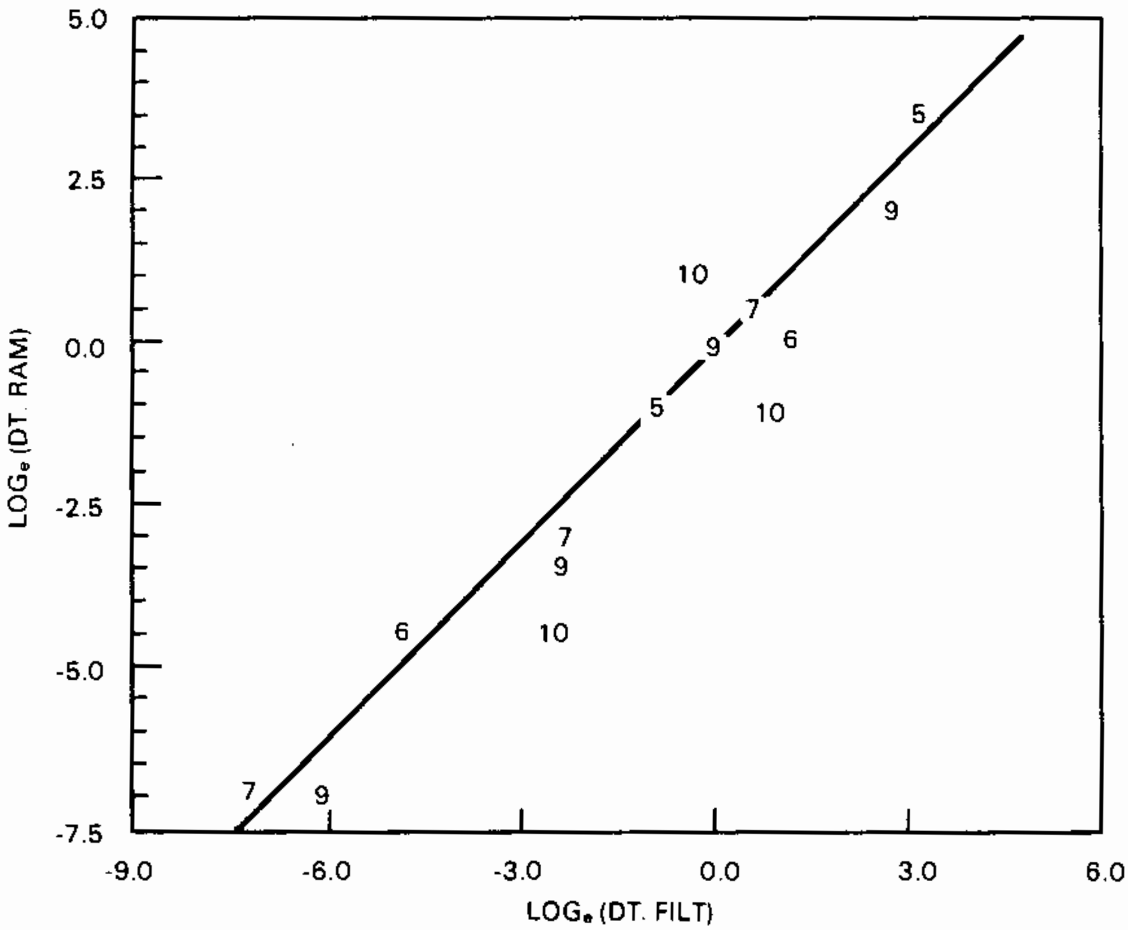

FIGURE 3.9. Comparison of Depletion Rates for Sequential RAM-1 and Filters

This relationship was based on the 16 data pairs left after round 10, and the round 7, sequence E points were removed. Figure 3.10 is a plot of the data and the fitted line. The round 10 and round 7.E points are circled as a reminder that they were not included in the fit. When they were included in the fit, 87.4% of the variability in the filter data was accounted for by the fit to the RAM-1 data. This R^2 improved to 97.2% when the five unusual points were removed. The correlation coefficients were 0.935 with all 21 data points and 0.986 with the 16 data points.

The logarithmic scale complicates use of the relationship but is necessary to prevent the few high concentrations (20 mg/m^3 and above) from determining the relationship. A plot of the untransformed data would have 14 points in the

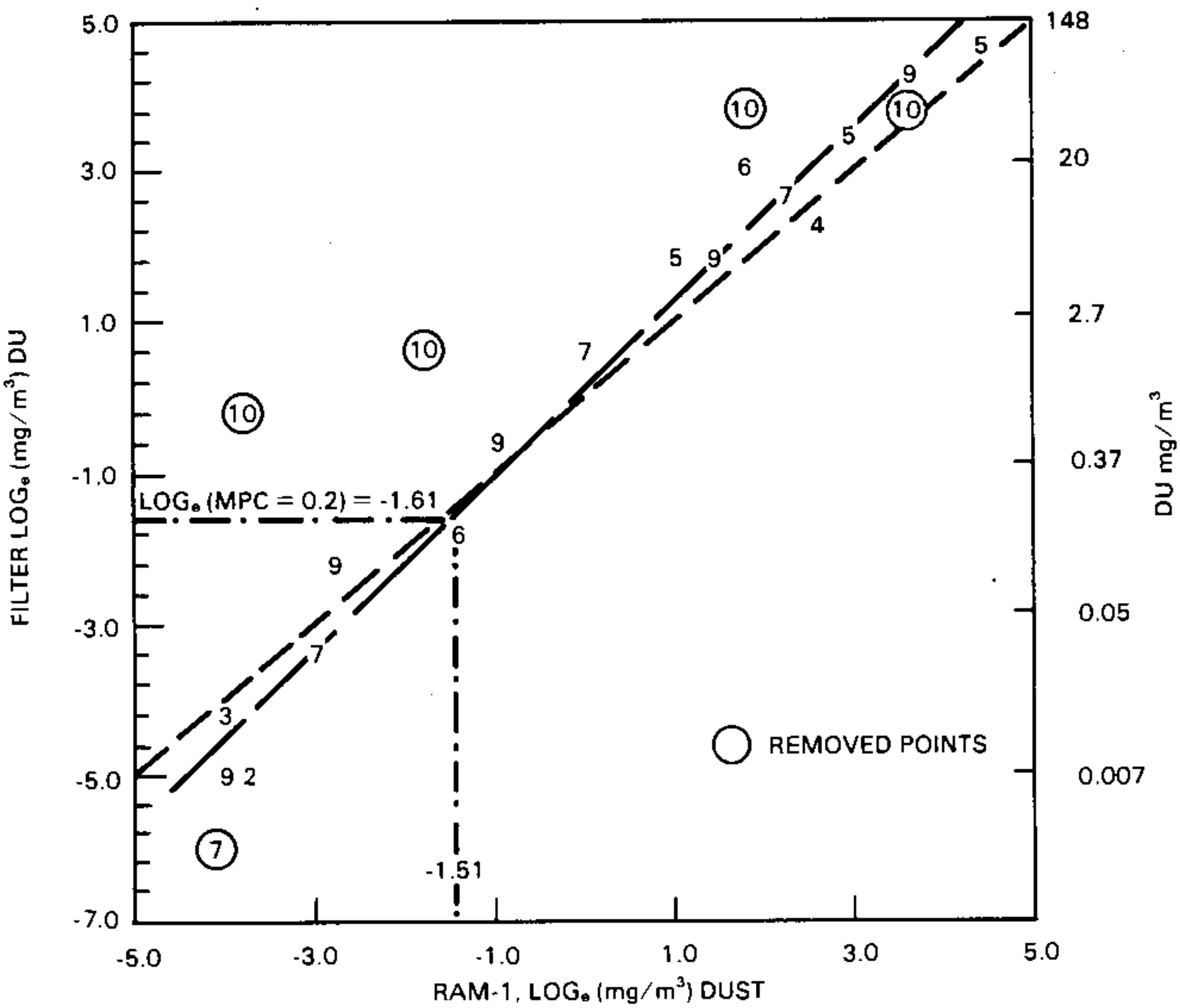

FIGURE 3.10. Least-Squares Fit of Sequential Filter to RAM-1 $\log_e$ (DATA)

0- to 5-mg/m^3 sector with the other 8 points sparsely distributed out toward the 100-mg/m^3 extremes. On the logarithmic scale the relationship is not far from $\log_e(F) \doteq \log_e(R)$, as indicated by the dashed line in Figure 3.10. The intercept, 0.095, is not statistically significantly different from zero, but the slope is statistically greater than unity. Since these differences are on the logarithmic scale, they become practically significant when exponentiated to transform back to the mg/m^3 scale. Use of the logarithmic scale implies that the underlying relationship is

$$F = a' R^b$$

so that

$$\log_e (F) = \log_e a' + b \log_e (R)$$

The fit gave the estimates

$$a = \log_e a' = 0.0949$$

and

$$b = 1.12668$$

Then

$$a' = \exp (0.0949) = 1.10 \text{ mg/m}^3$$

and, for example, if a RAM-1 result were 10 mg/m^3,

$$\hat{F} = 1.10 (10)^{1.12668} = 14.73 \text{ mg/m}^3 \text{ of DU.}$$

Using the relationship inversely at the MPC we have,

$$\log_e (R) = [\log_e (0.2) - 0.0949]/1.12668 = -1.5127$$

and

$$\exp (-1.5127) = 0.2203 \text{ mg/m}^3 \text{ of dust.}$$

Since both the RAM-1 and filter analyses are subject to imprecision on the order of 10 to 20% of the reported values and since a relative bias is apparent between the two measurement methods, these point estimates and the applicability of the statistical methods used to get them are questionable.

The final conclusion is that the expected qualitative relationship between the RAM-1 and sequential filter data is confirmed, but the fit is not accurate enough to "calibrate" the RAM-1 to give grams of DU. The inverse calculation does indicate that 0.5 mg/m^3 for respirable particles is conservative, since the 0.2 mg/m^3 DU MPC corresponds to 0.22 mg/m^3 of dust.

3.8 RESULTS FOR THE RDM-301 MONITOR

This instrument did not provide sufficient data for comparisons with other measuring instruments. Two rounds had no results. Rounds 2, 7, 9, and 10 had 0.0 mg/m^3 reported and the results for rounds 3 and 4 are suspect due to an adjacent air sampler.

3.9 COMPARISONS OF RESULTS FOR THE TSI-3500 AND OTHER SAMPLERS

The hand-held TSI-3500 is used as a back-up check on the Inlet Monitor (RAM-1). The measurements from these two instruments have a correlation of 0.810, indicating a fairly strong relationship. The scatterplot of Figure 3.11 shows that round 4 strongly influences the relationship. The correlation improves slightly to 0.845 with round 4 removed. Figure 3.11 suggests a quadratic relationship between the TSI and Inlet RAM-1 results, but this is based on the single round 4 point. With all ten rounds included

$$TSI = 0.012 + 0.3755\ (INLET)\ ,$$

but with round 4 removed

$$TSI = -0.0069 + 1.1561\ (INLET).$$

This last relationship, with an intercept not significantly different from zero and a slope near unity, is more in line with expectations for instruments sampling respirable particulates. The line estimated with round 4 removed is plotted in Figure 3.12. No other sampler, either routine or special filters, had a meaningful correlation with the TSI results. It might be expected that the RAM SEQ.E data would be related, but the correlation was only 0.132. Other correlations with TSI were:

Sampler	INFILT	WKFILT	INCYC	WKCYC
r	0.080	-0.121	0.226	-0.585

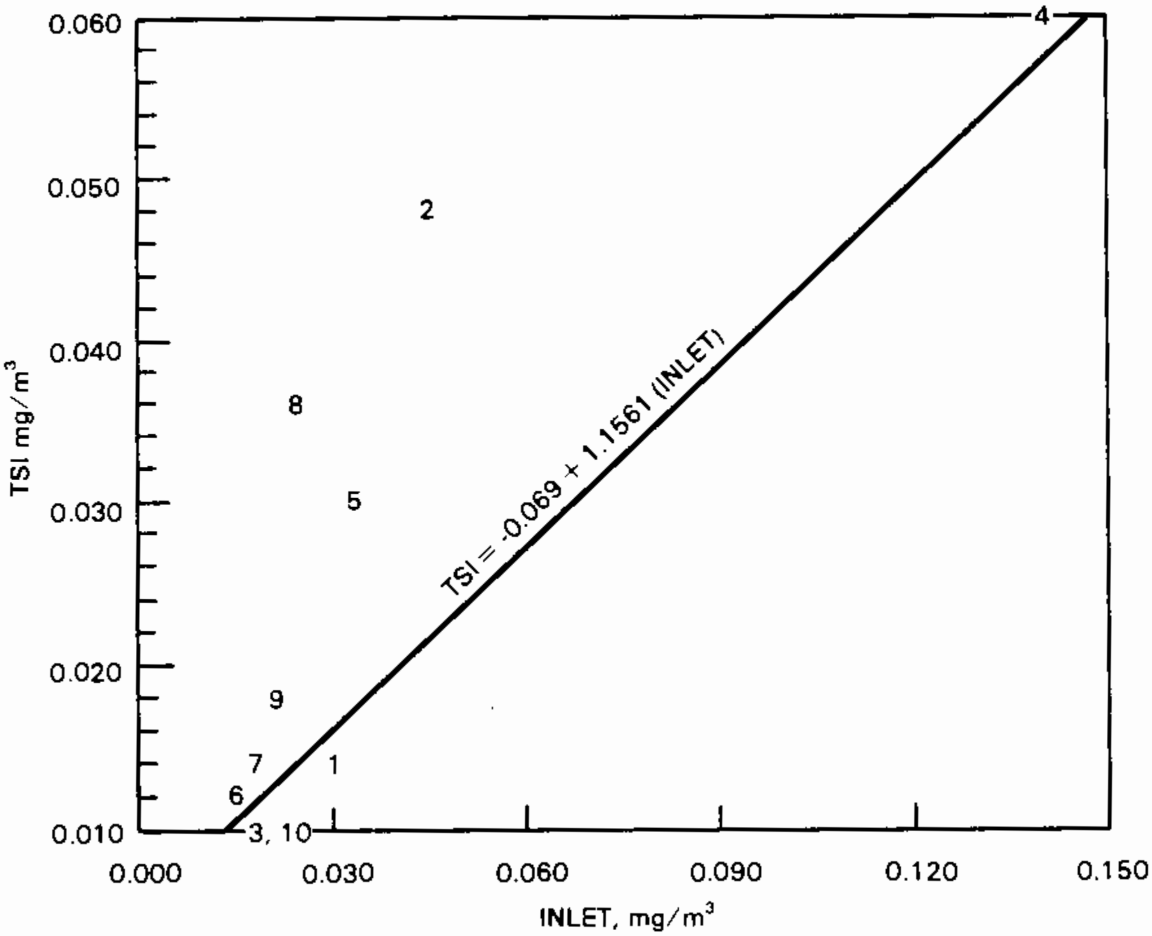

FIGURE 3.11. Plot of TSI Versus Inlet RAM-1, with Round Number

The sequential-filter samples D and E had correlations of 0.911 and 0.875 due to the large values for round 4 (30.5 for sequence D and 5.0 for sequence E). Without round 4 these correlations dropped to -0.756 and -0.751, respectively, based on four data points.

3.10 WIPE DATA ANALYSIS

The wipe data from Ford's Farm were analyzed to determine if counts increased from the wipes over the series of 10 rounds and to discover the degree of variability in the amount of material deposited on the various surfaces within the building. The beta-gamma counts were used for the analysis.

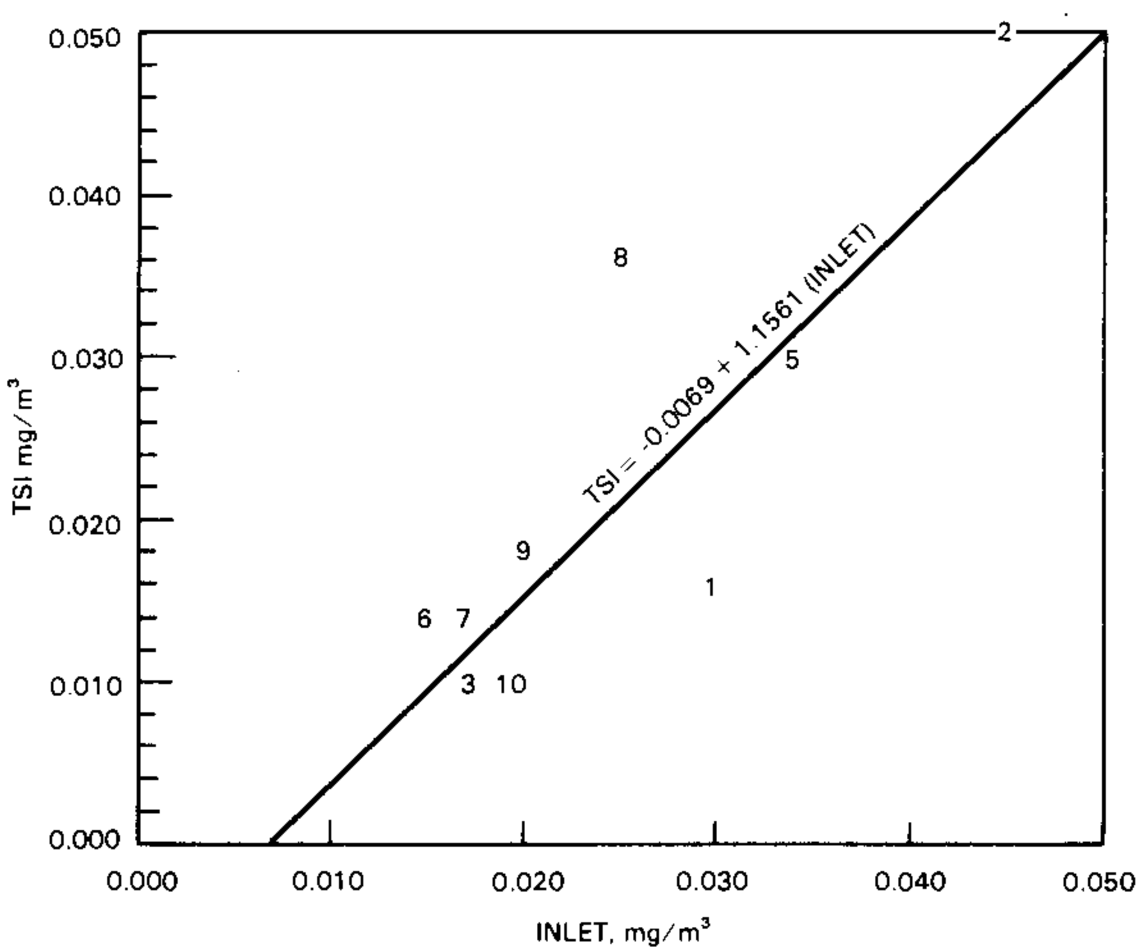

FIGURE 3.12. Linear Fit of TSI to Inlet Data, round 4 Removed, with Round Number

The wipe data were for five surfaces: target and x-ray film apparatus on the floor, exhaust side wall, x-ray side wall, rear wall, and front wall. Wipes were taken from four to nine locations on each of these surfaces after each round and after the decontamination wash-down between Rounds 3 and 4. Not all locations were wiped after each round; for example, round 1 had beta-gamma wipes for only 3 of the 33 locations.

The beta-gamma data in counts per minute, are given in Appendix C. The locations where the wipe samples were taken are given in Figure 3.13. The average counts over the 10 rounds and the decontamination for each location and the whole surface is also shown. For the exhaust wall, the averages combining all wipes in the exhaust duct and the other three locations are given separately. There were no beta-gamma data for location 24 on the x-ray wall.

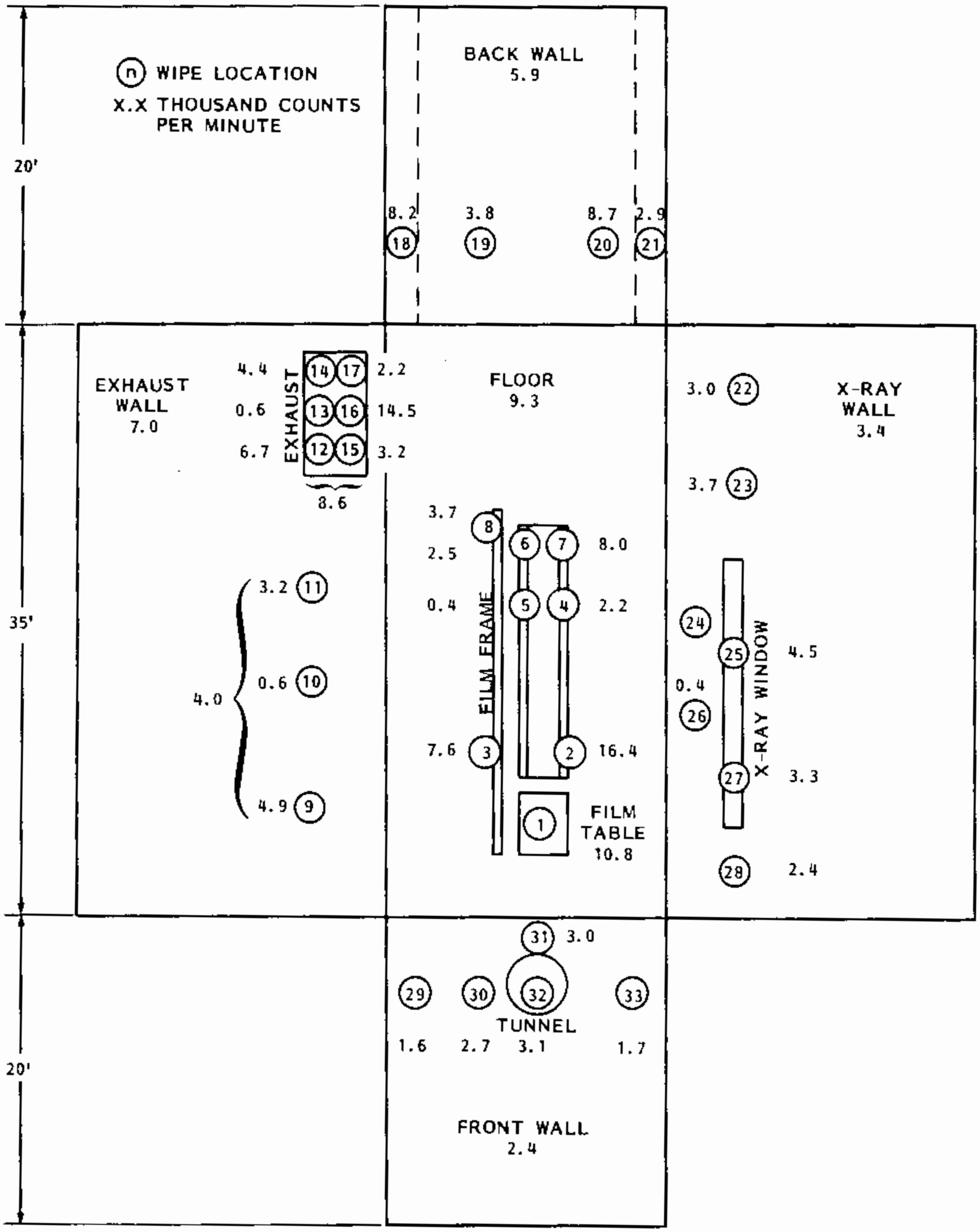

FIGURE 3.13. Sampling Locations with Average Thousand Counts per Minute

Table 3.12 gives the ranges of averages and data for the surfaces with the most extreme differences. The average of all wipes for the five locations on the front wall was 2.4 thousand counts and for the equipment on the "floor," 9.3 thousand. For each of these surfaces, the extreme averages are given for specific locations with at least four wipes on the surface. For example, on the front wall, wipe location 29 has 1.6 thousand and location 32 has 3.1 thousand beta-gamma counts (Figure 3.13). These averages over the shots indicate how the locations on a surface might be expected to vary. The round-to-round row gives the minimum and maximum concentration observed for the rounds at the specific location.

Table 3.12 shows that the floor equipment had about four times as much contamination as the front wall. The averages in Table 3.13 show the ranking of the subsurfaces and indicate a significant concentration difference for the areas defined, a 6.9 thousand count difference overall. The exhaust entry area is almost as contaminated as the floor equipment; a significant drop to the rear wall average is followed by less pronounced changes for the other vertical surfaces.

The ranking of the rounds based on beta-gamma counts and Inlet RAM-1 concentrations are compared at the bottom of Table 3.14. There is fair agreement among ranks, the Spearman rank correlation coefficient being 0.706. However rounds 5 and 10 do have quite different rankings based on the two measurement methods.

TABLE 3.12. Minimum and Maximum for Wipe Data and Averages (thousands of β,γ counts)

Surface	Front Wall		Floor	
Surface Average	2.4		9.3	
Location on Surface	29 Left	32 Tunnel	Front 8 Film Frame	2 Rail
Average	1.6	3.1	3.7	16.4
Round-to-Round Range After Decontamination	1.3 to 3.7	1.6 to 6.4	0.2 to 8.3	10 to 62.6

TABLE 3.13. Ranking of Subsurfaces

Surface	Floor Equipment	Exhaust Entry	Rear Wall	Exhaust Wall	X-Ray Wall	Front Wall
Average	9.3	8.6	5.9	4.0	3.4	2.4
Rank	1	2	3	4	5	6
Change		0.7	2.7	1.9	0.6	1.0

TABLE 3.14. Wipe Summary

Location	Code	β,γ Avg	Rank
Floor Equipment	1, 2, 3, 7, 8	9296	1
Exhaust Wall	9, 11	4016	4
Exhaust Duct	12, 14, 16	8563	2
Rear Wall	18, to 21	5909	3
X-Ray Wall	22, 23, 25, 27, 28	3393	5
Front Wall	29 to 33	2420	6
Wall Only		2248	
Tunnel		3101	
Overall		5600	

Round	1	2	3	4	5	6	7	8	9	10
β/γ Rank	6	9	1	10	3	2	4	7	5	8
Inlet Rank	7	9	2.5	10	8	1	2.5	6	5	4

The counts for round 3 were greater than those for round 2. The building was washed down (decontaminated) after round 3; however, the counts were greater after round 4 than after round 3, and stayed at roughly the same level for rounds 4 through 10. This pattern is evident in the plots of the natural logarithms of the data given in Appendix C.2. These plots mark the time of decontamination with a vertical line. Aside from the initial effect, seen in the first three rounds, the wipe data do not indicate a build-up in deposited material over successive rounds. The logarithmic scale of the plots masks the magnitudes of the differences in counts. The average of the natural log data for round 3 was about 7.82. After decontamination the average dropped to 6.24 and for rounds 4 through 10 it was 8.44. Exponentiating these averages (to base e), gives the geometric mean of the counts. These were, roughly: 2500 counts for round 3 (500 counts after decontamination), and 4600 for rounds 4 through 10. Decontamination decreased the smearable contamination by a factor of five, but the next shot raised it to about twice the level for round 3, where it remained for the next 5 rounds. The trend slightly increased over rounds 4 through 10 for the back wall.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis of the data, several conclusions are drawn that are relevant to the operation of the sampling system and the use of the results obtained. The section with supporting discussion is referenced in parenthesis.

4.1 EXHAUST SAMPLERS

1. For the exhaust particle sampler the gross alpha analyses only slightly underestimate the DU content as determined by radiochemical analysis. (3.5)
2. The exhaust concentration should be calculated as the average of the left and right samples. The results of the left and right samples correlated well. (3.5)
3. The observed average DU-exhaust concentrations were <0.006 mg/m^3. These do not correlate well with the long-term exhaust monitor averages. We conjecture that this is because of the procedure used for deriving the average from the strip charts and because the values are at the very bottom of the monitor's range and are imbedded in signal noise and zero drift. This means that the RAM-1 is not a suitable instrument for monitoring exhaust concentrations. It may be useful for monitoring filter integrity. (3.3)
4. The exhaust monitor indicated concentration excursions exceeding 0.008 mg/m^3 for 6 out of 10 test rounds. The excursions averaged 8.4 min, and none exceeded 15 min in duration. The concentrations were characterized by a sharply inclined pulse when the shot was fired, followed by a longer gradually declining release lasting no more than 20 min. (3.4).

4.2 WORKPLACE SAMPLERS

1. Data were insufficient for comparing the RDM-301 readings with any of the other samplers because most readings were recorded as below detection limits. (3.8)

2. No significant relationships between the inlet monitor and any other target bay sampler except the sequential filter samples are apparent. (3.6 and 3.7)

3. The rates-of-concentration decline of the inlet monitor and the sequential samples showed significant correlation, the rates being nearly the same. Monitor respirable-dust concentration readings were lower than the sequential samplers' total DU concentrations. Depletion rates declined with sequence and varied from round to round. This shows that the monitor indicates a concentration change at the correct time and rate within the time resolution of the sequential samples, and probably quicker than that. (3.7)

4. The analysis of the limited data predicts that on the average the inlet monitor readings would be about 0.220 and 0.064 mg/m^3 for DU concentrations of 0.200 and 0.050 mg/m^3 respectively (the two action levels potentially of interest). (3.7)

5. The TSI-3500 readings when the target bay door was opened correlated well (0.845) with the inlet monitor in the range encountered (<0.05 mg/m^3). (3.9)

6. The two total-particulate samples taken on either side of the target bay correlated well (0.818) with each other. The concentration at the inlet was usually no more than two times higher than at the workplace position. (3.6)

In terms of the test objectives listed in Section 2.2, Table 4.1 gives the correlations obtained for the comparisons listed.

4.3 SMEARABLE SURFACE CONTAMINATION

1. The mean target bay smearable contamination varied by a factor of four from the least (2,400 counts/wipe) to the greatest (10,300 counts/wipe). In increasing order of contamination the surfaces are ranked as: front wall, x-ray wall, exhaust wall, rear wall, exhaust inlet, and floor equipment. (3.10)

TABLE 4.1. Correlations for Comparisons of Major Interest

Exhaust RAM-1	versus Exhaust DU Sample	0.39 Excluding DL values, (3.4)
Inlet RAM-1	versus Inlet DU as function (rate) of time	0.977 between depl. rates, (3.7)
Inlet RAM-1	versus Inlet DU (readings)	0.935 (0.986 without round (3.9) 10 and 7.E)
Inlet RAM-1	versus Inlet respirable DU (INCYC)	-0.075 (3.6)
RDM-301	Versus Workplace DU	Insufficient data (3.8)
RDM-301	Versus Workplace respirable DU	Insufficient data (3.8)
TSI-3500	Versus Inlet RAM-1	0.810, (3.9)
TSI-3500	Versus RDM 301	Insufficient Data (3.9)

2. A low-pressure, water-spray decontamination after three test shots decreased the smearable surface contamination by a factor of 5. Contamination increased to almost twice predecontamination levels after the following shot and stayed there for the next five shots. (3.10)

4.4 RECOMMENDATIONS

Recommendations for performing target bay and ventilation exhaust sampling are based on the above conclusions.

- Discontinue use of the RDM-301 because of its lack of sensitivity, slow response, and time-consuming maintenance.
- Implement weekly air samples in the workplace at two or more locations to better determine occupational exposure.
- Implement ways to reduce the labor required to operate the air sampling system such as airflow controls, easier data recording, and monitor maintenance.

Some additional experiments are recommended:

- After workplace air sampling is implemented, monitor exposure of a subject in the target bay using a personal sampler to collect weekly samples.
- Compare these samples with the fixed samplers to test how well fixed samplers alone would routinely estimate exposures.
- Test target bay monitor and sampler responses using artificially generated surrogate aerosols.

A lower priority experiment would be to determine how accurately the exhaust monitor indicates a release exceeding the control level. This could be done by collecting air samples in the exhaust ducts for no more than 30 min after a test shot. Several sequential samples or a single sample could be taken. If sequential sampling is done it is important to use consistent exposure intervals. A better method for determining monitor readings accounting for zero drift would be useful for this experiment.

Finally, particle-size measurements in the unfiltered exhaust duct would be useful if upgrading the ventilation filtration system is contemplated. Aerodynamic particle-size distribution for DU and total particles is needed for selecting air-cleaning equipment. Cascade impactors or a device using a laser velocimetry would be the methods of choice.

5.0 REFERENCES

Application for Amendment of Aberdeen Proving Ground License Sub-834. 1980. U.S. Army Material Testing Directorate, Aberdeen Proving Ground, Maryland.

Glissmeyer, J. A., and M. A. Halverson. 1980. Operating Manual for Ford's Farm Range Air Samplers. PNL-3361, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

BASIC DATA FOR FORD'S FARM

APPENDIX A

BASIC DATA FOR FORD'S FARM

TABLE A.1. Exhaust Monitor and Sampler Concentrations[a]

Round	Monitor mg/m^3 EXH.M	Uranium Concentration By Fluorimetry $Ci \times 10^{-18}/ml$ EXH.L	EXH.R
1	0.0024	1.900	2.600
2	0.0010	0.413	0.267
3	0.0020	-0.520	-0.680
4	0.0035	1.500	1.800
5	0.0030	1.400	1.500
6	-0.0010	0.190	0.710
7	-0.0010	0.290	0.370
8	0.0010	1.100	0.660
9	-0.0010	0.210	0.290
10	0.0029	1.700	1.800

TABLE A.2. Average Monitor Aerosol Concentration In Workplace, mg/m^3 (Concurrent with Temporary Samplers)

Round	RDM	INLET	TSI
1	---	0.030	0.015
2	0.0	0.045	0.049
3	0.010	0.017	0.010
4	0.008	0.140	0.059
5	---	0.034	0.030
6	0.140	0.015	0.013
7	0.0	0.017	0.014
8	0.020	0.025	0.036
9	0.0	0.020	0.018
10	0.0	0.019	0.010

TABLE A.3. Uranium Concentration Analyses by Fluorimetry, Temporary Samplers

Round	Uranium Ci x 10^{-18}/ml INFILT	INCYCL	WKFILT	WKCYCL[a]
1	0.264	0.260	-0.790	19.000
2	3.030	0.350	1.870	-32.000
3	6.830	0.852	4.050	-6.250
4	6.830	0.852	4.050	-6.250
5	24.600	0.686	17.900	25.100
6	24.600	0.686	17.900	25.100
7	0.992	0.620	0.400	30.000
8	27.000	8.300	16.000	-0.640
9	2.400	0.910	0.820	-13.000
10	8.100	0.200	20.000	58.000

(a) A minus sign indicates a "detection limit" value.

TABLE A.4. Average Inlet Monitor Aerosol Concentration by Sequence After Shot, mg/m^3[(a)]

Round	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	---	---	---	---	---
2	---	0.022	---	---	---
3	---	0.017	---	---	---
4	---	---	13.100	1.990	0.090
5	---	77.000	41.000	22.000	2.700
6	---	5.700	1.500	0.260	0.032
7	---	9.100	1.050	0.055	0.017
8	30.600	11.400	4.100	0.890	0.050
9	37.000	4.200	0.380	0.060	0.020
10	---	34.000	6.000	0.170	0.024

(a) A minus sign indicates a "detection limit" value.

TABLE A.5. Temporary Sequential Sampler[a] by Fluorimetry

	Uranium Ci x 10^{-15}/ml				
Round	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	---	---	---	---	---
2	2.700	0.0037	---	---	---
3	1.800	0.0058	---	---	---
4	100.000	24.000	3.400	---	---
5	120.000	33.000	---	11.000	1.8000
6	64.000	7.1000	---	0.085	0.0048
7	64.000	4.4000	0.590	0.014	-0.0012
8	---	---	---	---	---
9	25.000	1.8000	0.230	0.048	0.0023
10	130.000	18.0000	15.200	0.764	0.2910

(a) A minus sign indicates a "detection-limit" value.

APPENDIX B

BLANK ADJUSTMENT FOR TEMPORARY SAMPLERS

TABLE B.1. X_{ij}, Basic Data, Ci/ml, Uranium by Fluorimetry[(a)]

	Ci x 10^{-18}/ml						Ci x 10^{-15}/ml				
Round	EXH.L	EXH.R	INF	INC	WKF	WKC	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	1.900	2.600	0.264	0.260	(0.790)	19.000	--	--	--	--	--
2	0.413	0.267	3.030	0.350	1.870	(32.000)	2.700	0.003	--	--	--
3	(0.520)	(0.680)	6.830	0.853	4.050	(6.250)	1.800	0.005	--	--	--
4	1.500	1.800	6.830	0.853	4.050	(6.250)	100.000	24.000	3.400	--	--
5	1.400	1.500	24.600	0.686	17.900	25.100	120.000	33.000	--	11.000	1.800
6	0.190	0.710	24.600	0.686	17.900	25.100	64.000	7.100	--	0.085	0.005
7	0.290	0.370	0.992	0.620	0.400	30.000	64.000	4.400	0.590	0.014	(0.001)
8	1.100	0.660	27.000	8.300	16.000	(0.640)	--	--	--	--	--
9	0.210	0.290	2.400	0.910	0.820	(13.000)	25.000	1.800	0.230	0.048	0.002
10	1.700	1.800	8.100	0.200	20.000	58.0D0	130.000	18.000	15.200	0.764	0.291

(a) Parentheses indicates detection limit values.

TABLE B.2. V_{ij}, Air Volume Sampled, m^3[(a)]

	Ci x 10^{-18}/ml						Ci x 10^{-15}/ml				
Round	EXH.L	EXH.R	INF	INC	WKF	WKC	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	4.9850	4.9850	1.5900	2.4000	1.6300	0.0640	--	--	--	--	--
2	10.3000	10.3000	1.7300	2.6199	1.7800	0.0700	0.2760	0.9729	--	--	--
3	8.6999	8.6999	3.6500	5.4800	3.5100	0.1440	0.2460	0.8060	--	--	--
4	5.1500	5.1500	3.6500	5.4800	3.5100	0.1440	0.1350	0.1350	0.1350	0.3240	0.3780
5	9.1999	9.1999	3.5399	5.2500	3.0399	0.1199	0.1350	0.1350	0.1350	0.0540	1.6200
6	8.3500	8.3500	3.5399	5.2500	3.0399	0.1199	0.1620	0.1080	--	0.1620	0.5400
7	7.4000	7.4000	1.5200	2.2500	1.4600	0.0579	0.1350	0.1350	0.1350	0.4320	1.2699
8	7.5000	7.5000	1.5200	2.2500	1.5200	0.0599	0.1350	0.1350	0.1350	0.3240	0.3200
9	8.1499	8.1499	1.5200	2.5200	1.5200	0.0599	0.1350	0.1350	0.1080	0.1620	1.3700
10	8.6499	8.6499	3.4800	5.1799	3.3800	0.1340	0.1350	0.1350	0.2700	0.4050	0.4050

(a) Table B.3 is calculated by dividing the blank filter analysis by the figures in Table B.2.

TABLE B.3. b'_{ij}, Blank Ci/ml

Round	Ci x 10^{-18}/ml EXH.L	EXH.R	INF	INC	WKF	WKC	Ci x 10^{-15}/ml SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E	b_j, Blank[a] Ci/Filter
1	0.2122	0.2122	0.6654	0.4408	0.6490	16.5312	--	--	--	--	--	(1.058)
2	0.1027	0.1027	0.6115	0.4038	0.5943	15.1142	0.0038	0.0010	--	--	--	(1.058)
3	0.1216	0.1216	0.2898	0.1930	0.3014	7.3472	0.0043	0.0013	--	--	--	(1.058)
4	0.2330	0.2330	0.3287	0.2189	0.3418	8.3333	0.0088	0.0088	0.0088	0.0037	0.0031	1.2
5	0.0380	0.0380	0.0988	0.0666	0.1151	2.9166	0.0025	0.0025	0.0025	0.0064	0.0002	0.35
6	0.3832	0.3832	0.9039	0.6095	1.0526	26.6666	0.0197	0.0296	--	0.0197	0.0059	3.2
7	0.0324	0.0324	0.1578	0.1066	0.1643	4.1379	0.0017	0.0017	0.0017	0.0005	0.0001	0.24
8	0.1733	0.1733	0.8552	0.5777	0.8552	21.6666	0.0096	0.0096	0.0096	0.0040	0.0009	1.3
9	0.0073	0.0073	0.0394	0.0238	0.0394	1.0000	0.0004	0.0004	0.0005	0.0003	0.0000	0.06
10	0.1223	0.1223	0.3040	0.2042	0.3130	7.8956	0.0078	0.0078	0.0039	0.0026	0.0026	(1.058)

(a) Parenthesized value is average of rounds 4 through 9.

TABLE B.4. X'_{ij}, Adjusted Ci/ml[a,b,c]

Round	Ci x 10^{-18}/ml EXH.L	EXH.R	INF	INC	WKF	WKC	Ci x 10^{-15}/ml SEQ.A	SEQ.B	AC.C	SEQ.D	SEQ.E
1	1.687	2.387	-0.401	-0.180	(0.140)	2.468	--	--	--	--	--
2	0.310	0.164	2.418	-0.053	1.275	(16.885)	2.696	0.002	--	--	--
3	(0.398)	(0.558)	6.546	0.659	3.748	(-1.097)	1.795	0.004	--	--	--
4	1.266	1.566	6.501	0.634	3.708	(-2.083)	99.991	23.991	3.391	--	--
5	1.361	1.461	24.501	0.619	17.784	22.183	119.997	32.997	--	10.993	1.799
6	-0.193	0.326	23.696	0.076	16.847	-1.566	63.980	7.070	--	0.065	-0.001
7	0.257	0.337	0.834	0.513	0.235	25.862	63.998	4.398	0.588	0.013	(0.001)
8	0.926	0.486	26.144	7.722	15.144	(-21.026)	--	--	--	--	--
9	0.202	0.282	2.360	0.886	0.780	12.000	24.999	1.799	0.229	0.047	0.002
10	1.577	1.677	7.795	-0.004	19.686	50.104	129.992	17.992	15.196	0.761	0.288

(a) The results in Table B.4 are obtained by subtracting the results in Table B.3 from those of Table B.1.
(b) Parentheses indicate detection limit values.
(c) A minus sign indicates samples for which blank correction was greater than sample result.

TABLE B.5. P_{ij}, Blank as a Percentage of the Unadjusted Data[a]

Round	EXH.L	EXH.R	INF	INC	WKF	WKC	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	11.17	8.16	252.04	169.55	82.16	87.00	--	--	--	--	--
2	24.87	38.47	20.18	115.37	31.78	47.23	0.14	29.38	--	--	--
3	23.38	17.88	4.24	22.63	7.44	117.55	0.23	22.63	--	--	--
4	15.53	12.94	4.81	25.67	8.44	133.33	0.00	0.03	0.26	--	--
5	2.71	2.53	0.40	9.71	0.64	11.62	0.00	0.00	--	0.05	0.01
6	201.70	53.97	3.67	88.85	5.88	106.24	0.03	0.41	--	23.23	123.45
7	11.18	8.76	15.91	17.20	41.09	13.79	0.00	0.04	0.30	3.96	15.74
8	15.75	26.26	3.16	6.96	5.34	3385.41	--	--	--	--	--
9	3.50	2.53	1.64	2.61	4.81	7.69	0.00	0.02	0.24	0.77	1.90
10	7.19	6.79	3.75	102.12	1.56	13.61	0.00	0.04	0.02	0.34	0.89

(a) Table B.5 is calculated by taking the values in Table B.3 as a percentage of corresponding values in Table B.1.

TABLE B.6. U_{ij}, Grams DU per Cubic Meter of Air[a]

	g/m^3						mg/m^3				
Round	EXH.L	EXH.R	INF	INC	WKF	WKC	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	4.688	6.632	-1.115	-0.502	0.391	6.857	--	--	--	--	--
2	0.861	0.456	6.717	-0.149	3.543	46.904	7.489	0.007	--	--	--
3	1.106	1.551	18.167	1.833	10.412	-3.047	4.988	0.012	--	--	--
4	3.519	4.352	18.058	1.761	10.300	-5.787	277.753	66.641	9.419	--	--
5	3.783	4.060	68.056	1.720	49.402	61.620	333.326	91.659	--	30.537	4.999
6	-0.536	0.907	65.822	0.212	46.798	-4.351	177.722	19.639	--	0.181	-0.003
7	0.715	0.937	2.316	1.425	0.654	71.839	177.772	12.217	1.633	0.037	0.002
8	2.574	1.351	72.624	21.450	42.068	-58.407	--	--	--	--	--
9	0.562	0.785	6.557	2.461	2.168	33.333	69.443	4.998	0.637	0.132	0.006
10	4.382	4.660	21.655	-0.011	54.686	139.179	361.089	49.978	42.211	2.114	0.801

(a) Mass units were calculated by converting units from Table B.4.

TABLE B.7. $\log_e (U_{ij})$, Natural Logarithm of Adjusted Grams DU per m^3[(a)]

Round	EXH.L	EXH.R	INF	INC	WKF	WKC	SEQ.A	SEQ.B	SEQ.C	SEQ.D	SEQ.E
1	1.5450	1.8920	--	--	-0.9379	1.9253	--	--	--	--	--
2	-0.1486	-0.7845	1.9047	--	1.2650	3.8481	2.0134	-4.9257	--	--	--
3	0.1013	0.4389	2.8996	0.6060	2.3430	--	1.6070	-4.3848	--	--	--
4	1.2582	1.4708	2.8936	0.5659	2.3321	--	5.6267	4.1993	2.2428	--	--
5	1.3305	1.4014	4.2203	0.5425	3.8999	4.1209	5.8091	4.5180	--	3.4189	1.6093
6	--	-0.0968	4.1869	-1.5491	3.8458	--	5.1802	2.9775	--	-1.7079	--
7	-0.3348	-0.0643	0.8402	0.3548	-0.4238	4.2744	5.1805	2.5028	0.4910	-3.2875	-5.8751
8	0.9454	0.3014	4.2852	3.0657	3.7393	--	--	--	--	--	--
9	-0.5746	-0.2419	1.8805	0.9008	0.7738	3.5065	4.2405	1.6091	-0.4504	-2.0226	-5.0724
10	1.4776	1.5390	3.0752	--	4.0016	4.9357	5.8891	3.9115	3.7426	0.7490	-0.2217

(a) Results are natural logarithms of values in Table B.6.

APPENDIX C.1

LISTING OF BETA-GAMMA DATA FROM WIPES

APPENDIX C.1

LISTING OF BETA-GAMMA DATA FROM WIPES

TABLE C.1. Wipe Data for X-Ray Wall, cpm

Round	LOC22.B Mean	LOC23.B Mean	LOC24.B Mean	LOC25.B Mean	LOC26.B Mean	LOC27.B Mean	LOC28.B MEAN
1	--	--	--	--	144	--	--
2	119	214	--	161	747	1119	133
3	--	3281	--	3688	--	4474	5172
4	2411	--	--	4550	--	2194	--
5	--	5186	--	7578	--	1744	--
6	--	5928	--	4861	--	1683	--
7	3922	--	--	--	--	3284	2422
8	1725	--	--	1394	--	2511	1105
9	8216	--	--	4300	--	9516	4033
10	1792	--	--	9786	--	6450	3888
Decon	--	--	--	--	--	144	272
Mean	3030.8	3652.2	--	4539.7	445.5	3311.8	2432.1
N	6	4	0	8	2	10	7

TABLE C.2. Wipe Data for Front Wall, cpm

Round	LOC29.B Mean	LOC30.B Mean	LOC31.B Mean	LOC32.B Mean	LOC33.B Mean
1	--	112	--	--	--
2	200	235	232	--	109
3	368	6367	--	358	1172
4	--	3467	--	--	--
5	--	3467	1633	1584	1695
6	2078	--	1394	1578	--
7		2811	3744	2639	2167
8	3684	--	6230	6127	2355
9	1300	--	4317	2994	678
10	1715	--	3658	6427	3442
Decon	--	--	--	--	--
Mean	1557.5	2743.1	3029.7	3101.0	1659.7
N	6	6	7	7	7

TABLE C.3. Wipe Data for Floor, cpm

Round	LOC1.B Mean	LOC2.B Mean	LOC3.B Mean	LOC4.B Mean	LOC5.B Mean	LOC6.B Mean	LOC7.B Mean	LOC8.B Mean
1	--	--	--	400	--	--	--	--
2	204	--	--	125	747	425	877	1656
3	10800	1242	9505	1684	--	--	--	10291
4	4834	--	2150	--	--	4678	--	233
5	39611	--	11250	--	--	--	25472	987
6	7772	10044	11711	--	--	--	--	4711
7	7361	--	4478	6394	--	--	--	5161
8	1016	11639	7205	--	--	--	--	499
9	10505	11538	7111	--	--	--	4184	3567
10	25840	62569	7619	--	--	--	1323	8300
Decon	361	1155	--	--	50	--	--	1544
Mean	10830	16364	7628	2150.7	398.50	2551.5	7964	3694.8
N	10	6	8	4	2	2	4	10

TABLE C.4. Wipe Data for Exhaust Wall, cpm

Round	LOC9.B Mean	LOC10.B Mean	LOC11.B Mean	LOC12.B Mean	LOC13.B Mean	LOC14.B Mean	LOC15.B Mean	LOC16.B Mean	LOC17.B Mean
1	--	--	--	--	--	--	--	--	--
2	109	586	361	1825	575	274	137	--	211
3	1950	--	1652	--	--	--	3410	20750	2154
4	2678	--	4125	6011	--	--	6594	--	4083
5	2583	--	9894	14011	--	5794	--	38994	--
6	--	--	464	19227	--	5383	--	10266	--
7	1786	--	1277	--	--	10350	--	12922	--
8	--	--	--	8500	--	1885	--	11622	--
9	3133	--	1510	2255	--	4300	--	12443	--
10	21905	--	5942	1172	--	7356	--	7908	--
Decon	--	--	--	972	--	222	2461	1077	--
Mean	4877	586	3153.5	6746	575	4445.5	3150.5	14497	2149.3
N	7	1	8	8	1	8	4	8	3

TABLE C.5. Wipe Data for Rear Wall, cpm

Round	LOC18.B Mean	LOC19.B Mean	LOC20.B Mean	LOC21.B Mean
1	--	--	--	--
2	--	175	337	204
3	--	393	3180	1849
4	1333	2678	--	3294
5	2394	4756	9750	577
6	4106	3411	16033	2711
7	2272	2605	5228	1628
8	3705	1605	11183	2700
9	39433	9999	12966	7422
10	4119	8650	19669	5346
Decon	--	--	627	--
Mean	8194	3808.0	8774	2859.0
N	7	9	9	9

APPENDIX C.2

PLOTS OF BETA-GAMMA DATA FROM WIPES BY ROUND

NATURAL LOGARITHM OF DATA

APPENDIX C.2

PLOTS OF BETA-GAMMA DATA FROM WIPES BY ROUND
NATURAL LOGARITHM OF DATA

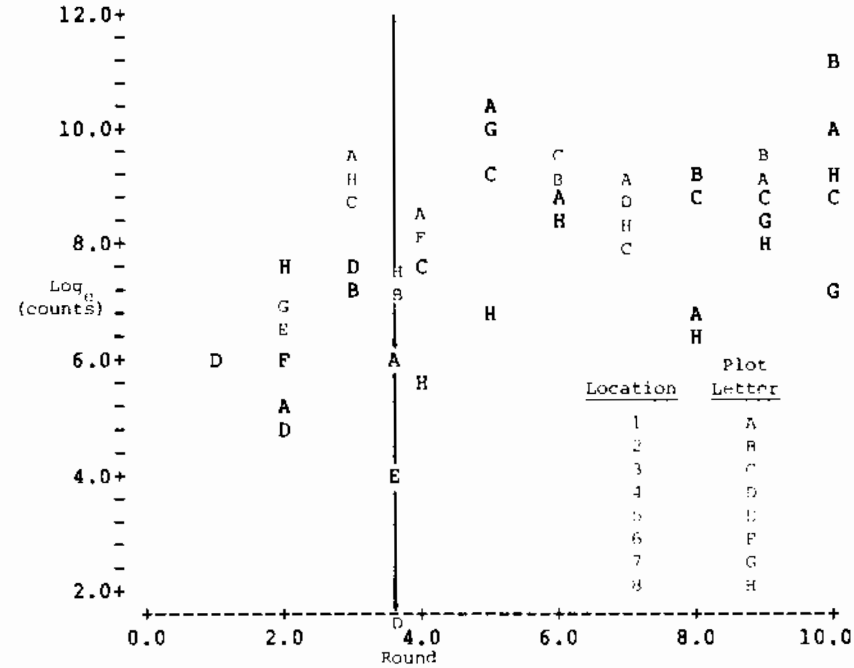

FIGURE C2.1. Log_e (counts) by Round for Floor Samples

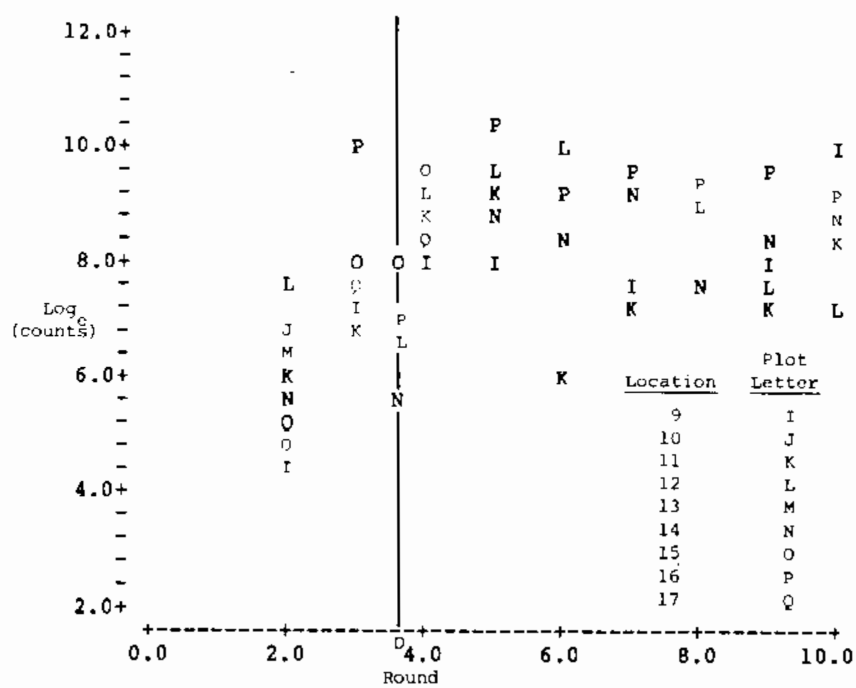

FIGURE C2.2. Log_e (counts) by Round for Exhaust Wall

NOTE: Vertical line indicates time at which building was decontaminated.

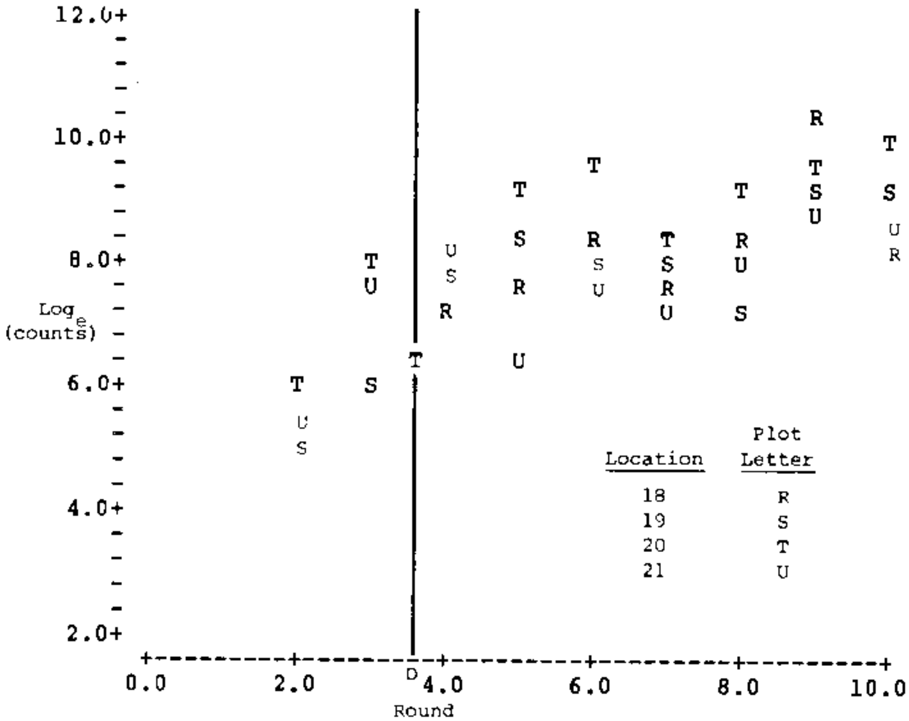

FIGURE C2.3 Log$_e$ (counts) by Round for Back Wall

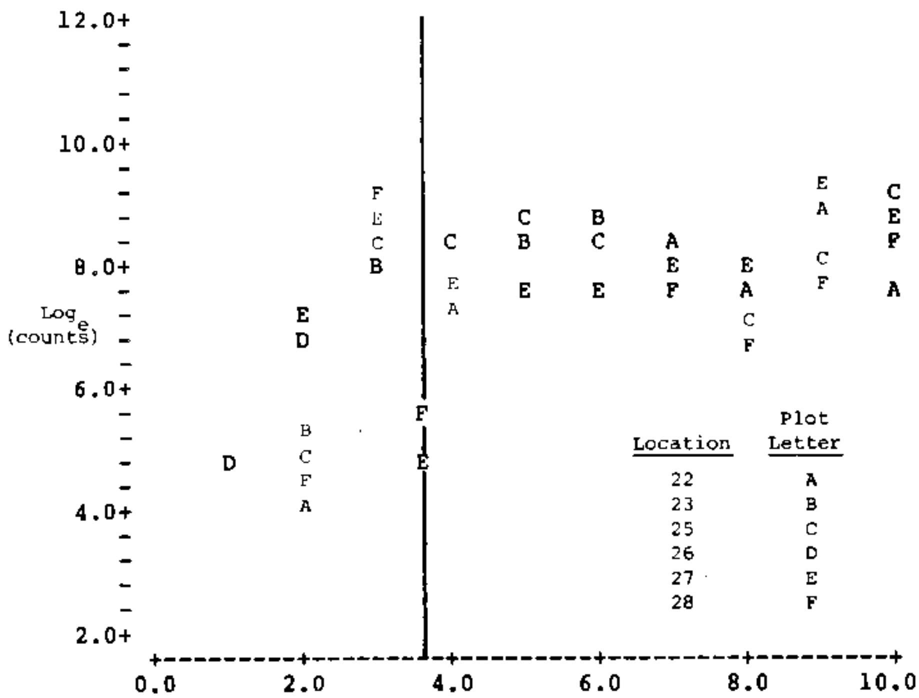

FIGURE C2.4. Log$_e$ (counts) by Round for X-Ray Wall

NOTE: Vertical line indicates time at which building was decontaminated.

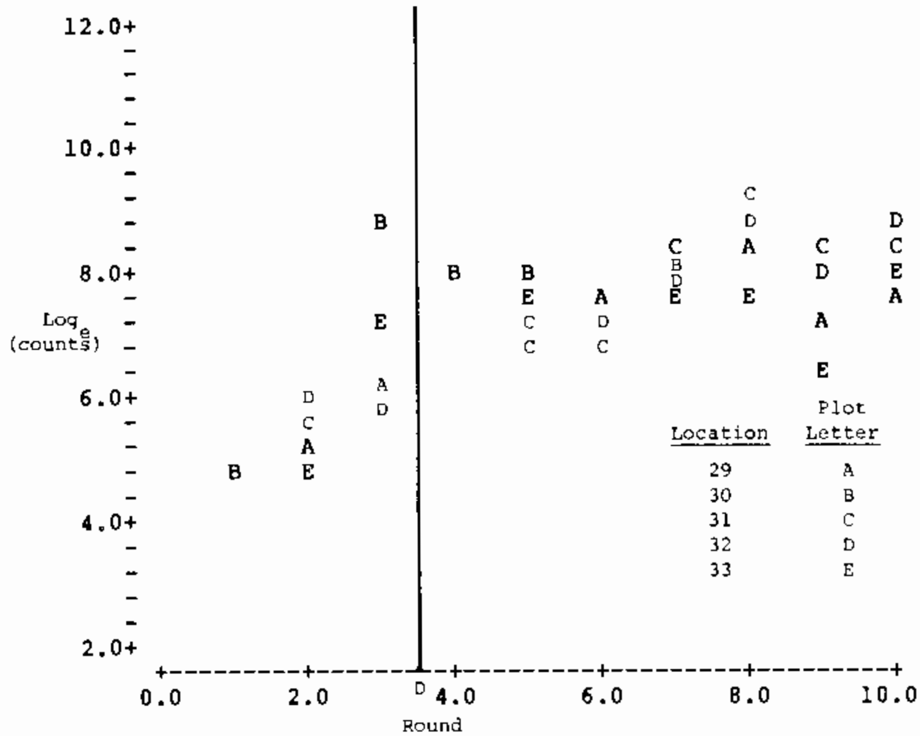

FIGURE C2.5 Log_e (counts) by Round for Front Wall

NOTE: Vertical line indicates time at which building was decontaminated.

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