

Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory

Title

EFFECTS OF ENERGY CONSERVATION MEASURES ON AIR HYGIENE IN PUBLIC BUILDINGS:
FINAL REPORT

Permalink

<https://escholarship.org/uc/item/3x17z22h>

Author

Dimmick, R.L.

Publication Date

1980-02-01



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

EFFECTS OF ENERGY CONSERVATION MEASURES ON AIR HYGIENE
IN PUBLIC BUILDINGS: FINAL REPORT

R. L. Dimmick and H. Wolochow

February 1980

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782.*



DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

EFFECTS OF ENERGY CONSERVATION MEASURES
ON AIR HYGIENE IN PUBLIC BUILDINGS:
FINAL REPORT

R.L. Dimmick, Ph.D., Chairman
Aerosol Sciences Department

and

H. Wolochow, Ph.D., Chairman
Environmental Sciences Department

Naval Biosciences Laboratory
School of Public Health
University of California, Berkeley

February 1980

Prepared under UCLBL P. O. No. 4500210 for the Energy Efficient Buildings Program, Energy and Environment Division, Lawrence Berkeley Laboratory. Principal Investigators: Craig Hollowell and Arthur Rosenfeld.

The work described in this report was funded by the Office of Buildings and Community Systems, Assistant Secretary for Conservation and Solar Energy of the U.S. Department of Energy under contract No. W-7405-ENG-48.

TABLE OF CONTENTS

Table of Contents.	I
List of Tables and Figures	II
Executive Summary.	S1 - S6
INTRODUCTION	1
Section A. In-House Filter and Ventilation-Rate Efficiency Tests	1
Section B. Carondelet High School	4
Section C. Fairmoor School, Columbus, Ohio.	6
Section D. Long Beach Naval Hospital	9
Section E. Long Beach Naval Hospital Studies in 1979. . . .	32
Section F. Sampling at Social Services Building, San Francisco.	34
Section G. Sampling near a Cast Room at the Veteran's Hospital, Martinez, California	37
Section H. Sampling in a Men's Restroom	37
CONCLUSIONS	39
RECOMMENDATIONS	40
LITERATURE CITED	40

II

LIST OF TABLES AND FIGURES

Table 1s.	Mean Values (No. per cubic meter) of numbers of airborne colony-forming particles at various sites.. . . .	S-5
Table 1A.	Raw data list of three sequential tests in the wind-tunnel chamber with contrasts of means between stations and between runs.	3
Table 1B.	Mean, Maximal % variation, with time between sample stations, 3 runs.	3
Table 1C.	Mean, Maximal % Variation, between 3 runs.	3
Table 2A.	Mean numbers of CFP/m ³ in classrooms, Fairmoor School . . .	8
Table 2B.	List of CFP at Fairmoor School: Special conditions of significance were respirable particles at 1:00 p.m., in Room 12.	8
Table 2C.	Mean values of CFP/m ³ in classrooms as a function of time.	8
Table 3A.	Means and standard deviations by location and stage. (Includes only those samples which were taken at exactly the same time in all 3 locations.).	11
Table 3B.	Pearson correlation coefficients for colony forming units/m ³ for Andersen Sampler stage with location.. . . .	12
Table 3C.	Analysis of variance - Long Beach Naval Hospital	13
Table 4.	Mean values of CFP/m ³ found in air, Social Welfare Building, San Francisco, Ca.. . . .	35
Table 5.	Number of particles/ft ³ found in air, Social Welfare Building, San Francisco, Ca.	35
Figure 1.	Concentration of CO ₂ (ppm) by time of day, Carondelet High School, June 1, 1978.	5
Figure 2.	Particle size distribution (by Andersen stage) CFU/m ³ Long Beach Naval Hospital, Sept. 18, 1978.	14
Figure 3.	Long Beach Naval Hospital, Sept. 19, 1978.	15

List of Figures: Cont'd.

Figure 4.	Long Beach Naval Hospital, Sept. 20, 1978.	16
Figure 5.	Long Beach Naval Hospital, Sept. 21, 1978.	17
Figure 6.	Long Beach Naval Hospital, Sept. 22, 1978.	18
Figure 7.	Long Beach Naval Hospital, Oct. 16, 1978.	19
Figure 8.	Long Beach Naval Hospital, Oct. 17, 1978.	20
Figure 9.	Long Beach Naval Hospital, Oct. 18, 1978.	21
Figure 10.	Long Beach Naval Hospital, Oct. 19, 1978.	22
Figure 11.	Long Beach Naval Hospital, Oct. 20, 1978.	23
Figure 12.	Changes in airborne particle concentration with time: Cast Room, Long Beach Naval Hospital	25
Figure 13.	Variation of the number of particles in air of corridor outside Orthopaedic Cast Room, Long Beach Naval Hospital, Oct. 16, 1978.	26
Figure 14.	Variation of the number of particles in air of corridor outside Orthopaedic Cast Room, Long Beach Naval Hospital, Oct. 17, 1978.	27
Figure 15.	October 18, 1978	28
Figure 16.	October 19, 1978	29
Figure 17.	October 20, 1978	30
Figure 18.	Comparison of size distribution of total particles to those containing viable bacteria; Long Beach Hospital, Cast Room.	31
Figure 19.	Comparison of size distribution, bacteria and fungi; Men's Room - NBL	38

STUDIES OF EFFECTS OF ENERGY CONSERVATION MEASURES
ON AIR HYGIENE IN PUBLIC BUILDINGS

EXECUTIVE SUMMARY

R. L. Dimmick and H. Wolochow

Naval Biosciences Laboratory

The objective of this subcontract was to provide scientific, technical and materiel support to the Lawrence Berkeley Laboratory (LBL) ventilation studies group, regarding sampling, assay, and data analysis of the airborne bacterial content of hospitals and educational facilities. Our major task was to estimate the magnitude of change in the numbers of airborne microbes as a function of ventilation practice and changes thereof (retrofit).

Four task areas were initially selected for action or study. The first task was to design, build, test, and operate field-type samplers for airborne bacteria. The Andersen sampler was selected over other types of samplers because of its convenience, reliability, acceptability (as reported in the literature) and its capacity to segregate collected particles into size ranges. Design criteria for a field unit to be used in classroom or operating room were that it must house two samplers, operate these samplers according to a selected schedule, remain silent (no louder than a properly operated household refrigerator), not permit the internal temperature to rise above 37°C, be inconspicuous (resemble furniture), and be as tamper-proof as possible. After two mock-ups were tested, three field units were constructed, tested and operated successfully in the field.

A second task was intended to be supplemental to field work in that it comprised concurrent studies of effects of assay medium and sampling methods (e.g., location, type of media container, inlet diameter) on the apparent quantitative and qualitative recovery of airborne microbes. From such studies we hoped to improve the efficiency of field sampling.

A third task involved testing effects of low (20%) to moderate (80%) particle collection efficiencies of filters combined with varied amounts of high-efficiency filtered fresh air input on the removal of microbial aerosols generated within the test space. The purpose was to study effects of fresh-to-recirculating air ratios and particulate filters necessary to maintain a desired removal rate of microbes originating in hospital spaces. In the field, conditions must be accepted as found, and until a large number of habitats are tested, the variety of potentially useful conditions limits the scope of the study. In the laboratory, the variation of conditions to be tested can be made widespread in a relatively short time.

A fourth task comprised basic studies directed toward finding better and less expensive methods of sampling airborne virus. At present, the methodology for studying airborne virus is primitive contrasted to bacterial collection methods, and we were aware that respiratory illnesses are caused principally by virus. The project was dropped after 1 year as being too basic to be considered a part of the over-all ventilation program.

If airborne virus and bacteria both originate from activities of humans, then their relative amounts should remain more or less constant as activity or ventilation conditions change.

Field Studies

The reader should refer to the previous Annual Report (LBID-04S, EEB-Vent 79-1) for detailed description of the aerosol samplers. Briefly, samplers operate by causing air to be drawn at almost sonic velocity through holes in a series of six perforated plates (stages). The holes decrease in size from the top (Stage 1) to the last plate (Stage 6). Semi-solid growth medium is placed under each plate. The largest particles in the air being sampled collect on stage 1 ($\geq 8 \mu\text{m}$) the smallest on stage 6 (0.8 to $1 \mu\text{m}$ in diameter) and intermediate sizes are collected between stage 1 and 6 in 4 more-or-less overlapping ranges. In general, 20-minute samples were taken at 5:00 - 6:00 a.m. (Control) and at 10:00 a.m., 1:00 p.m. and 3:00 p.m.

If a particle contains at least 1 living bacterial cell that is able to grow (form a visible spot on the medium called a "colony") then that particle is termed a "Colony-forming-particle" (CFP)* Larger particles have a higher probability of containing at least one living microbe than smaller particles, so if the particles originate from a single source (say, the human) the larger particles have an enhanced probability of being detected.

The sampling modules were operated at nine "field" sites: (a) the LBL Energy Test House at Walnut Creek; (b) Peralta Hospital; (c) Carondelet High School; (d) Long Beach Naval Hospital, Long Beach, California (3 visits); (e) Fairmoor Elementary School, Columbus, Ohio; (f) an office building in San Francisco, and other sites selected for test purposes.

Table 1s lists mean values of the colony-forming particles (CFP) found in one cubic meter of air at the various sites.

Airborne bacteria inside buildings arise principally from human activity. In classrooms, where activity is structured, the numbers are high when class is in session, low when it is unoccupied. In hospitals, the numbers fluctuate but show little tendency toward a time-dependent variation during a work-day. Other fluctuations in hour-to-hour

*Used in both singular and plural sense.

or day-to day counts are caused by random air patterns (e.g., someone walks rapidly past a sampler when the sample is being taken). Altogether, the variability of either sequential or equivalent (e.g., the 10:00 a.m. sample for 2 weeks) samples is such that the standard deviation is about equal to the mean value.

As a result, unless mean values differ by greater than 2-fold, usual statistical methods are of little value in determining whether or not two sample groups vary significantly -- if the means vary 4-fold or greater then statistical methods are not needed. On the other hand, this fluctuating "bio-burden" of airborne microbes that can be inhaled has been shown to be the normal circumstance for occupied spaces. There is no criterion for an unacceptable level of this burden. Fortunately for mankind, the common types of airborne bacteria do not cause disease, nor is there evidence that the numbers of airborne, disease-causing microbes are related to these total numbers of airborne cells. Yet it is reasonable to believe that the level of "bio-burden" originating from a sick person, or one who sheds disease-causing types of germs (a "carrier" or "Typhoid-Mary") would double if the general bio-burden doubled as a result of decreased ventilation rate, and that the probability of the spread of disease by the airborne route would also double. The bio-burden, therefore, is an index of the potential for disease, but not an absolute criterion.

Each datum presented in Table 1s is an overall mean value, and is representative of a general level of bio-burden at the noted sites. The meaning of the extent of differences can only be derived subjectively.

Data from a ROYCO particle size analyzer (all particles capable of scattering light) were obtained during some field studies. The size distribution of both total particles and CFP are essentially log-normal but the mean diameters differ. The two "kinds" of particles could have arisen from the same source, but that is unlikely because there is no temporal correlation between absolute numbers of the two groups.

In-house studies showed: (a) that isokinetic* sampling is not required to collect representative samples of microbial aerosols found in occupied spaces because the very large particles that might contain microbes do not remain airborne in significant numbers for more than a few seconds; (b) that sampling from air ducts would be disadvantageous; (c) that a selected medium for Neisseria (a bacteria common to the human) could be used but the numbers were often less than 10% of the total; hence, the sensitivity to human activity was reduced; (d) that a surface-active agent could be applied to sampling media which would retard drying, thus allowing samples to be taken for periods as long as 2 hours; (e) that human activity sometimes caused measurable increases in numbers of bacteria contained in particles less than 5 μ m

*Isokinetic: Equal motion; to cause the air velocity within the sampler to equal the velocity of air to be sampled. To not do so sometimes causes a size-selective bias.

in diameter (1-5 μm diameter particles are considered to be in the "respirable" range), and (f) that a Petri plate containing three media types can be used in the samplers for purposes of species selection.

General Conclusions and Recommendations

The field samplers are satisfactory and we are convinced that any serious change in the airborne flora as a result of retrofit can be detected by the present methodology. Field-sampling should continue only if some epidemic condition seems to have been caused by a retrofit.

The following factors may be employed to reduce energy use in air conditioning practice without creating a severe increase in the bio-burden:

1. Medium to low-efficiency filters.
2. Reduce total volumetric flow rates.
3. Particulate filters with efficiency approximating 20 to 80% efficiency (ASHRAE Test) in air recirculating systems.

Significance of the Study to the Ventilation Program

The study has provided field sampling techniques and equipment that have been used to estimate the numbers of viable, airborne microbes in representative public buildings and could serve as a tool to monitor future retrofit situations. There is no evidence that any retrofit situation we have examined caused an increase in airborne microflora above that present in other, usual and common situations.

TABLE 1s

Mean Values (no. per cubic meter) of numbers
of airborne colony-forming particles at various sites.

CARONDELET HIGH SCHOOL

Fresh Air Ventilation Rate	Room 1		Room 2	
	A+	A-	A+	A-
13.3 cfm	160	54	107	27
2.0 cfm	115	47	75	37

(A+ = Class in session;
A- = Room unoccupied.)

RESEARCH HOUSE, Walnut Creek

Sealed and Vacant	Blower on
17	550

PERALTA HOSPITAL: Eye Operatory

Not in Use	In Use	Corridors
10	40	15

SPORTS ARENA, NSC

Not in Use	In Use
100	200

NBL: Conference Room

Not in use	Occupied
77	180
Men's Rest Room	132

FAIRMOOR ELEMENTARY SCHOOL

Ventilation:	Automatic	Manual	Sealed
	205	202	274

(Auditorium-Gymnasium had peak value of 1200)

Table 1s : Continued.

LONG BEACH NAVAL HOSPITAL:

	Cast Room	Patient Room	Proctology	
Set 1	523	100	62	
	Cast Room	Operatory	Obstetrics	Pediatrics
Set 2				
Patients	472 (3% <u>Staph. aureus</u>)			
No Patients	270	38		
Set 3	540	100	125	183

VETERAN'S ADMINISTRATION HOSPITAL : Martinez

Cast Room

333 (8% Staph aureus)

SAN FRANCISCO SOCIAL SERVICES BUILDING

	Waiting Room	Office (Cubicle for interviews)
Normal Ventilation	97	56
Reduced Ventilation	179	58

STUDIES OF EFFECTS OF ENERGY CONSERVATION MEASURES ON AIR HYGIENE IN PUBLIC BUILDINGS

R. L. Dimmick and H. Wolochow
Naval Biosciences Laboratory

INTRODUCTION

This report documents the results obtained during a year's continuation of a research project intended to measure the numbers of airborne bacteria in air of schools and hospitals before and after measures were taken to reduce the intake of outside air for ventilation purposes. The work was done by personnel of the Naval Biosciences Laboratory (NBL), School of Public Health, University of California, Berkeley.

The report of April 1, 1979, LBID-045, EEG-vent 79-1, entitled "Studies of Effects of Energy Conservation Measures on Air Hygiene in Public Buildings", by R.L. Dimmick and H. Wolochow, published by Lawrence Berkeley Laboratory (LBL), University of California, Berkeley, includes a section describing the equipment, materials, techniques of sampling and the research approach. That information is not repeated in this report except for the noting of any changes that have been made. A brief description of samplers and methodologies is included in the summary for this report.

The habitats sampled for effects of retrofit, and the dates selected for the efforts, were under the direction of the ventilation program team at LBL. Some additional sites were sampled by NBL personnel for the purpose of establishing a broader set of "background" data than the retrofit studies would have provided. When the first report was written, not all data from particulate and chemical studies were available. Also, analysis of some biological data had not been completed. This report, therefore, includes selected correlation analyses of studies done last year, as well as a report of an in-house investigation done to clarify some discrepancies previously noted in a study of clearance rates of air recirculated through moderately efficient filters.

A. IN-HOUSE FILTER AND VENTILATION-RATE EFFICIENCY TESTS

At the time of writing the 1st annual report, we had accumulated data sufficient to show that by recirculating air through moderately efficient filters (20-80%), we could achieve clearance rates of particles in the size range of importance to operator practice (3 μm to 10 μm), equivalent to that of 100% fresh-air intake. There were, however, some puzzling discrepancies in those data associated with volumetric recirculation rates of 400 ft^3/min . We noticed a few instances of apparent increases in the numbers of airborne, viable, test-bacteria had occurred after 60 minutes of recirculation time. We have now completed tests needed to show that these instances were artifactual.

In the original tests, three sampling stations were located within the test-chamber, each equipped with 4, four-stage Andersen samplers. Each sampler was operated at a designated time once during a run to avoid having personnel enter the room to change sampling medium as done in field

testing. In the new tests, five samplers were used at each station to permit increased evaluation of the time sequence.

In tests with the same protocol as that previously reported, we found a greater variation between sampling stations than between the variable ventilation parameters. Also, it is evident that at the low concentrations being sampled between the run-time interval of 30 to 60 minutes (during which anomalies were noted), large variations will occur because of well-known probability laws.

Table 1-(A,B,C) lists data from 3 (2 conditions) runs where reasonable equivalency of the tracer bacterium could be assured, and where a maximal contrast in ventilation conditions was being tested. The rationale for analysis of data in this simplified manner was that, with few data available (e.g., 3 sampling stations), a rule-of-thumb method for determination of a significant difference between two sets of numbers (or two numbers) is to note whether their values differ more than ± 2 times their square root.

In Table 1-A the maximal deviations observed, and the expected deviations calculated as the square root of 4 times the mean, are listed as percentages to permit a comparison between runs without also comparing effects of initial aerosol concentrations, which included experimental errors (e.g., variations in speed of the spinning top aerosol generator).

Mean deviations between data from sampling stations, with time, are listed in 1-B. With the exception of the value at 30 minutes, there was a time dependent change in variations from the mean: Initially the variation was moderate, became smaller, and then became maximal at 60 min. That result might be expected. The initial difference at "zero" time was caused by insufficient mixing. At 10 min. time, the aerosol was homogeneous (thoroughly mixed) but the numbers of colony-forming-particles (CFP*) remained high enough to be immune to small differences. (e.g., ± 5 in 100 CFP). Afterward, the numbers collected were so small that one colony -more or less --caused large, apparent variations. Regardless, these data show that the observed variability seldom exceeded values that might have been expected by Poisson statistics for the noted magnitudes.

Table 1-C lists deviations between runs, as above. The percentage deviation tends to increase as the numbers become smaller, and during the first 10-minute interval of aerosol time, they are less than the percentage deviations between sampling stations.(see 1-B). The low variation at "zero" times shows good replicability, run-to-run. It is also evident that a lowered circulation rate and lack of filters did not significantly decrease the clearance rate.

That is further demonstrated by examining the normalized decrease in CFP during the first 10 minutes, and at 30 minutes, also in Table 1-C. There is obviously no difference in clearance rates between runs if compared at 10 minutes run-time; there appears to be a difference at 30 minutes but one notes, by referring to the "raw" data, that the result is caused by a difference of only 4 CFP in a mean of 10 in run No. 57 -- hardly justification for believing that the difference is real.

*Used in both singular and plural sense throughout.

TABLE I

A. Raw data list of three sequential tests in the wind-tunnel chamber with contrasts of means between stations and between runs.

Run 57. Condition: No filters 200*** ft ³ /min ventilation rate							
Run Time Min.	No. Colony-forming Units/ft ³ air				Maximum Variation from Mean	Max. Var., %	Exptd. Var.%*
	Sta. 1	Sta. 2	Sta. 3	Mean			
0	1092	778	1242	1037	259	25	12
10	181	156	178	172	16	9	30
30	6	10	13	10	4	40	120
45	7	6	6	6	1	16	166
60	12	2	1	5	6	83	180

Run 58 Condition: 80% filters 400 ft ³ /min ventilation rate.							
0	1040	926	952	972	46	47	13
10	148	111	99	119	29	24	37
30	10	2	4	6	4	66	166
45	3	7	9	6	3	50	166
60	8	2	4	4	4	100	200

Run 59 Condition: 80% filters 400 ft ³ /min ventilation rate							
0	927	949	898	924	26	28	13
10	134	145	145	141	7	5	33
30	5	1	6	5	4	80	180
45	2	5	3	3	2	67	230
60	2	4	2	2	2	100	250

B. Mean, Maximal % Variation, with time between sample stations, 3 runs.

Station	Time				
	0	10	30	45	60
Percent					
1	25	9	40	16	83
2	47	24	66	50	100
3	28	5	80	67	100
Mean%	33	13	62	44	94

C. Mean, Maximal % variation, between 3 runs.						Normalized		
Time:	0	10	30	45	60	0	10	30
Run	Mean No. CFP							
57	1037	172	10	6	5	1.00	.166	.0006
58	972	119	6	6	4	1.00	.122	.0062
59	924	141	5	3	2	1.00	.152	.0054
P.M.V.**	5	19	43	40	125			

*Expected maximum variation = $\sqrt{4X}$ (mean)

**Percent maximal variation

***200 ft³/min equals 6 air changes per hour

In fact, at the concentration of airborne bacteria tracers that we were able to obtain initially, any points that have dropped to less than 10 percent can be considered to be effectively "zero", and variations or apparent periods of recovery at those levels are not significant. The tests could not have been done differently to avoid this low terminal level unless the initial level had been increased a minimum of ten-fold, a difficult task and one patently not cost-effective with respect to gain of information content of the results.

B. CARONDELET HIGH SCHOOL

Previous data obtained at this high school had shown a shift in particle size distribution as the school day progressed. We had speculated on possible explanations, but reached no firm conclusions.

When CO₂ data became available from the LBL team, we wondered whether biological effects might be related to changes in CO₂ content because it is known that trace amounts of other acid-forming gases (SO₂, NO₂) can change the pH of microbe-containing particles to an extent lethal for bacteria [1,2].

Measurements of CO₂ had been performed on essentially a continuous basis. We used a least squares approach to obtain best-fit data curves. Figure 1 shows a typical computer printout of these curves reconstructed from data points at 15 minute intervals. Also shown in the figure are over-all, mean values of the biological data previously collected, and the approximate line of best fit.

It is obvious that the CO₂ level is an excellent index of human activity. Data collected in one day were sufficient to illustrate the fact that activity in a school is directed, in contrast to other buildings where, in general, activity is "random" and continues through the noon hour. The well-defined "valley" at 12:00 noon shows this effect.

The number of CFP follows the same general trend, but there was no direct correlation, because the CFP decreased more rapidly as the day passed than the CO₂ did, and the level at the end of the day was less than prior to the start of classroom activity. To determine whether this decrease (perhaps a reduced survival capacity of airborne bacteria) might have been caused by CO₂ levels exceeding 800 ppm (note apparent divergence at about 10:00 a.m.) we dispersed test aerosols of the common "gut" organism, Escherichia coli, into controlled aerosol chambers containing 0, 800, and 1600 ppm of CO₂. There were no significant differences in the rates of death of airborne bacteria in any test, so the CO₂ content was not responsible for the divergence of data (12:00 noon to 4:00 p.m.) shown in Fig. 2.

The question is important because if CO₂, at these levels, did tend to kill airborne bacteria, and if a retrofit situation had tended to increase CO₂ levels, then the extent of any subsequent, real, increase in the dispersal of CFP would have been underestimated.

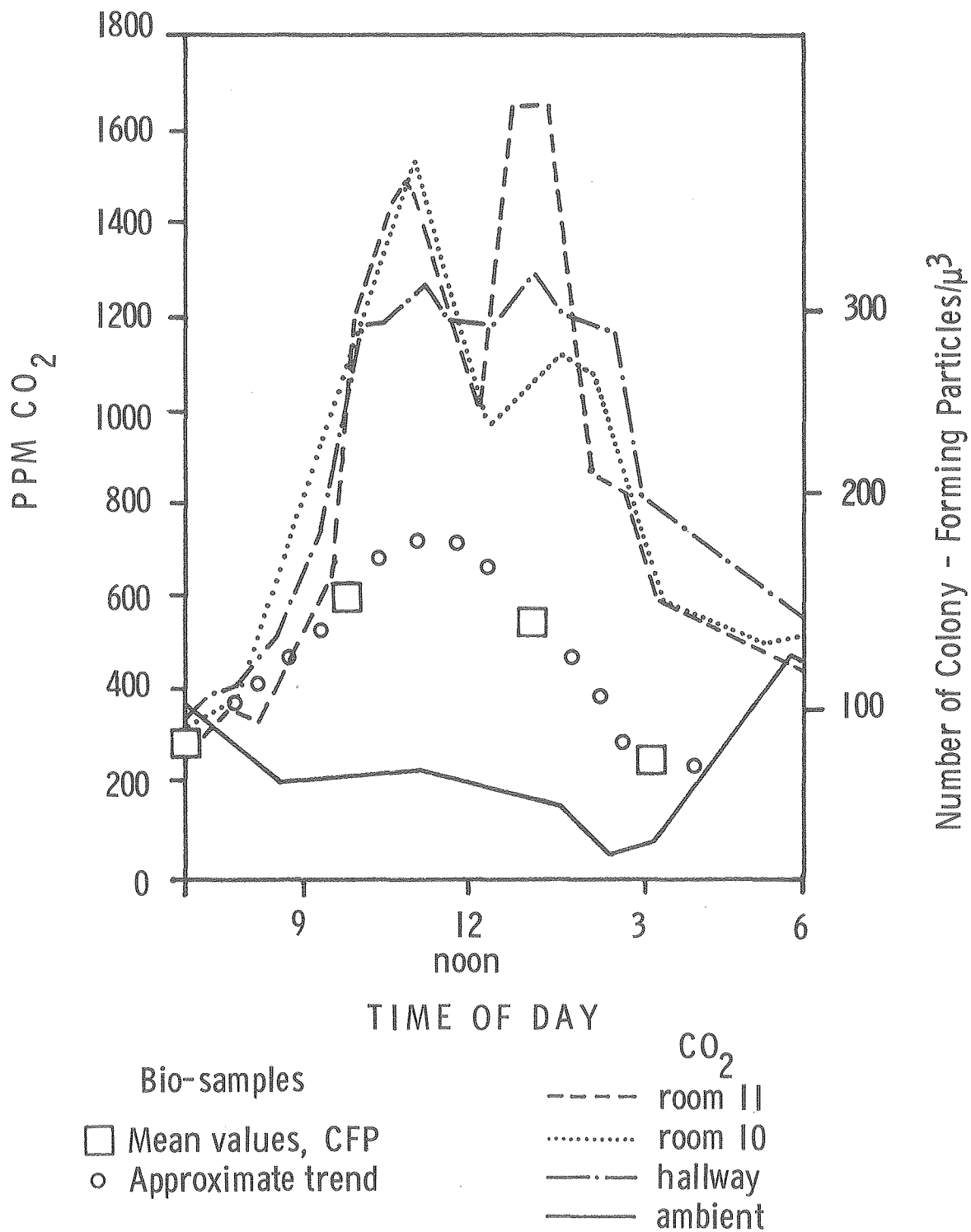


FIG. 1. Concentration of CO₂ (ppm) by Time of Day
Carondelet High School
June 1, 1978

C. FAIRMOOR SCHOOL, COLUMBUS, OHIO

This grade-school was examined by both the LBL and the NBL teams during January-February, 1979. A sampling station was located in each of two classrooms and a third was located in a combination Auditorium-Gymnasium. We had intended to obtain samples of the airborne particulate content at Fairmoor, but the RoyCo particle sampler, located in the LBL field van at Ames, Iowa, prior to the Columbus visit, became inoperable. By the time it was repaired, the Columbus sampling had been completed.

Each room in the school was equipped with a built-in air-vent heater system that could be set for either complete recirculation or as much as "100%" outside air. A manual or an automatic mode was available. In the automatic mode, the units were intended to supply variable amounts of outside air while maintaining a pre-set temperature. In the winter, outside air intake was minimal.

Three conditions were tested; automatic, manual (vents closed), and manual with sealed vents because vents did not close firmly enough to prevent the intake of significant amounts of outside air. The ventilation rates for these modes averaged 6.5, 4.9, and 1.5 cfm per person in the two classrooms respectively. Samples of airborne microbes were taken at 8:00 and 10:00 a.m., and at 1:00 and 3:00 p.m. The average numbers of colony-forming-particles/cubic meter of air (CFP/m³) for all samples are shown in Table 2A.

We have made a computerized search of the raw data to determine whether any parameter(s) might show a significant difference in any room, and noted that in one instance only, the case of respirable CFP in the 1:00 p.m. sample of Room 1, was there a significant increase caused by reduced ventilation. Data are shown in Table 2B. The t score of 3.70, a measure of difference with the noted P values which are levels of significance, shows that the assumption that there is no difference between automatic and sealed ventilation is false at better than the 99.99% confidence level. Examination of each room, individually, for a similar effect, showed no statistical difference, hence the effect was not a general one, and may have been incidental to ventilation conditions within that particular room. Deleting data collected from the auditorium did not reveal new statistically significant correlations.

Table 2C clarifies the pattern where mean values are listed in order of sample time. In a school, student activities are directed, and the time-sequence shows this.

A comparison of the over-all level of CFP under existing conditions at Carondelet with the level at Fairmoor, where almost double the number of CFP were found, is interesting. There is a greater percentage difference in the average number of CFP/m³ at Fairmoor (269, for classrooms only) when contrasted to the number at Carondelet (134, classrooms only), as there is when air in rooms at Fairmoor are contrasted in the ventilated or sealed condition (269:360). There was no evidence of a chronic, respiratory problem with students at Fairmoor. Thus, even if the increase as a result of ventilation changes at Fairmoor had been statistically significant, it could not possibly be considered a hazardous situation.

Contrariwise, the "background" (sampled before classes started) at Fairmoor was markedly lower than at Carondelet (30 contrasted to 75). The best explanation at this time is that Fairmoor was a "tight" structure, with little, non-intentional infiltration of outside air, whereas Carondelet High School (design requirements for different climates) may have been a "leaky" building. Another possible explanation is that the snow-covered ground at Fairmoor School prevented the dispersal of dust as a carrier for airborne microbes. This low base-line level at Fairmoor adds credence to the suggestion noted under Table 2C that in essence, the apparent difference between auto and sealed conditions might have been caused by excess infiltration of outside air at 1:00 p.m. in the "auto" mode, rather than excess particle build-up in the sealed mode. The question is intriguing, but of no practical value to retrofit studies.

The numbers of airborne CFP in the gymnasium-auditorium varied more than any other room tested at any site during the 2.5 yr period of sampling by this project. They varied from as low as $12/\text{m}^3$ to as high as $1200/\text{m}^3$ (one sample during sports activity). This was expected, since activity in the room also varied; sometimes it was crowded, sometimes there was very little activity during the day. The high variability prevented any analysis of the data in that room with respect to ventilation changes, but it does indicate that higher levels of airborne CFP can be tolerated by the human without evident harm than previous, mean levels of 50-200 might indicate. We can't estimate how much higher the tolerable level might be, but at least a mean concentration of CFP as high as $700/\text{m}^3$, or a maximal sample of $1200/\text{m}^3$, would have to be observed as a result of any ventilation change before one should be prompted to initiate additional studies.

TABLE 2A: Mean numbers of CFP/m³ in classrooms, Fairmoor School

Vent	Total Particles		Respirable Part.		Non-Respirable Particles	
	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
Auto	269	166	104	68	165	110
Manual	253	188	116	74	141	126
Sealed	360	206	182	118	177	99

(Because of the large standard deviations, there are no significant differences between any of these means. However, in each case, a consistent increase is evident between "auto" and "sealed".)

TABLE 2B: List of CFP at Fairmoor School: Special conditions of significance were respirable particles at 1:00 p.m., room 12.

Condition 1: (Automatic)

Condition 3: (Air intake taped shut)

Stage 5:

17, 12, 34, 51, 74, 32, 22, 35, 128, 127, 221, 122, 68, 36
31, 91.

Stage 4:

12, 22, 68, 36, 27, 75, 51, 12, 151, 108, 44, 151, 60, 60.
24, 34, 65.

DF = 30, t = 3.70, P .05 = 2.05: .01 = 2.75

TABLE 2C: Mean values of CFP/m³ in classrooms as a function of time.

Time	Auto	Manual	Sealed
8:00 a.m.	13	32	19
10:00 a.m.	243	148	305
1:00 p.m.	256*	323	403*
3:00 p.m.	291	280	370

(NOTE the difference between the starred () values. Since the vents were sealed, we were certainly not observing an infiltration of air containing numerous CFP, but perhaps rather clean, infiltrating air acting as a diluent under the Auto condition in that room.)

TOTALS: Auditorium S.D.

Auto	414	587
Manual	323	574
Sealed	418	442

D. LONG BEACH NAVAL HOSPITAL - Analysis of Previous Data

1. Potential of outdoor air ingress.

It had been intended that Long Beach Naval Hospital would be the model case of a pre- and post-retrofit study of a typical medical facility. As data collection proceeded, during the latter half of 1979, a decision was considered, and finally made that continued study was not required because of uncertainties in future operation and occupancy schedules at the hospital. The following results, therefore, are of possible interest in a public health sense, but are not applicable at this time to retrofit situations.

An initial sampling was done over a 6-week period (September-October 1978). The data available, at the time, were included in the 1978 annual report. We reported that the 5 a.m. sample during one week rose to an unusually high value (80-120 CFP/m³) as the week progressed, whereas that effect was not observed during a following week (20-30 CFP/m³). These were the only two weeks during that visit that 5 a.m. samples (intended as control or baseline data) were taken.

Was this effect caused by unusual humidity conditions-- We contacted the weather service, National Oceanic and Atmospheric Administration, and obtained weather printouts for those two weeks. There were no obvious correlations; in fact, the humidity was higher during the second week than the first; high humidity tends to induce better survival of airborne microbes than drier conditions.

We contacted the Chief Engineers Office at Long Beach and received a verbal report that during that week, a malfunction of a control system had caused air-intake fans, normally off at night, to remain running. Evidently we were observing the airborne flora in outside air that was being drawn into the building.

During one of the visits this year (1979; see Section E, below) we sampled outside air during the night hours at a station located on the roof. Sampling was implemented by use of a Bourdillon-type, slit-sampler that consists of a single slit through which air is drawn at impaction velocities onto a rotating petri plate, 20 cm in diameter. The motor-driven plate rotates once every 18 hours. Although the sampler is not truly quantitative, the colonies that arise on the medium provide a visual index of how numbers of airborne cells change during the sampling period. By counting colonies within limited segments, one can estimate the numbers per air volume (6 liters per minute) during intervals of about one-half hour. There is no capability of sizing microorganisms with this sampler.

We found fewer airborne microorganisms in outside air than we expected, but the number was highly variable, from as low as an estimated 20 CFP/m³ to periods where the numbers of colonies were too many to count. The latter could be at least 200/m³, so the ingress of outside air could account for the high numbers found inside the building.

During the roof-top sampling, we used some selective media to estimate numbers of the genera Staphylococcus, Neisseria, and Pseudomonas. There were no Neisseria, an occasional Pseudomonas and a few more Staphylococci (positive for growth on Mannitol-Salts), none of which were DNA-ase positive (not S. aureus species associated with disease-inducing types) (see Sec. E1).

The roof was checked for bird-roosts, but none was found.

The numbers of night-flora we observed are probably indicative of a general phenomenon of airborne microbes surviving better at night than day because of the well-known, lethal radiation effect of sunlight on airborne microbes, and the source(s) was probably diffuse.

2. Data analysis of indoor sampling.

We produced a computer-derived, cross-correlation analysis of data collected from Long Beach Naval Hospital in 1978 that provided us with variance and co-variance values of location, time, and stage number, all cross-correlated. This was done with the expectation that a similar treatment of data collected after retrofit could be contrasted with these data and that they might reveal whether significant changes in levels of CFP had occurred that would indicate the presence of unacceptable conditions.

The raw data, and computer printouts, occupy several volumes; they are too extensive to include in this report, and they reveal no important or unexpected correlations. They will remain in NBL archives for inspection, should that be needed. These data are probably illustrative, however, of conditions to be found in similar hospital structures and may serve to guide any future studies that may be undertaken, and as such, are suitable for inclusion in summary form.

Table 3A lists mean values and standard deviations at the various locations. Table 3B summarizes a Pearson correlation study. It illustrates only that there was a difference in both large and small particles, between the number of CFP associated with the Fracture room and Proctology. Table 3C summarizes the results of an analysis of variance. Again, the effect of locale shows a significant difference. Bar graph presentations, as shown in Figs. 2 through 11, are more meaningful in terms of visualized interpretation of the results than are tables. One can easily observe that the Cast Room location contained not only more large CFP than the other locations, but also more smaller CFP. The latter is of interest to us, albeit surprising, because we believe the increased number of CFP at the Cast Room location were formed by equipment used to remove casts, and we had not believed their type of equipment produced that many small particles, especially containing microbes in a viable condition.

Note that the vertical axis in figures 2 through 11 is shown as a log scale. Small visual differences in those figures represent rather large absolute differences. Compare the 5 a.m. samples during September (Figures 2 - 6) to the 5 a.m. samples during October (Figures 7 - 11). The presence

of substantial numbers of small CFP during September at that hour is obvious.

One may note also that there is a general tendency for the total number of CFP to increase as the patient load increases, though the correlation is not statistically supported. The sample-to-sample variation in the size distribution of the CFP is also evident in a more obvious way than when presented as lists of numbers.

TABLE 3A
Means and standard deviations by location and stage. (Includes only those samples which were taken at exactly the same time at all 3 locations.

Variable	Cases	Mean	SD
L1STAGE1	49	195.63	136.26
L2STAGE1	"	23.57	40.07
L3STAGE1	"	28.08	37.18
L1STAGE2	"	143.57	112.93
L2STAGE2	"	16.42	23.81
L3STAGE2	"	22.24	27.99
L1STAGE3	"	89.18	82.00
L2STAGE3	"	8.40	14.50
L3STAGE3	"	13.61	13.97
L1STAGE4	"	42.93	44.94
L2STAGE4	"	5.87	7.50
L3STAGE4	"	13.08	11.04
L1STAGE5	"	43.89	45.65
L2STAGE5	"	5.65	6.07
L3STAGE5	"	27.06	30.38
L1STAGE6	"	8.08	12.32
L2STAGE6	"	2.44	8.33
L3STAGE6	"	6.14	9.37
L1RSPPR	"	94.91	96.13
L2RSPPR	"	13.97	14.70
L3RSPPR	"	46.28	47.34
L1LGPRT	"	428.38	325.77
L2LGPRT	"	48.40	77.03
L3LGPRT	"	63.93	77.26
L1TOTPRT	"	523.30	408.47
L2TOTPRT	"	62.38	87.36
L3TOTPRT	"	110.22	116.02

L1 = Corridor adjacent to Fracture Room
L2 = Proctology Room
L3 = Room 116
LGPRT = Large particles : Stages 1-3
RESPPR = Respirable particles: Stages 4-6
TOTPRT = Total particles : Stages 1-6.

TABLE 3B

Pearson correlation coefficients for colony forming units/m³ for Andersen Sampler stage with location.

Correlation Test	Coef. of Var.	Cases	S
L1LGPR-T-L2LGPR-T	.454	49	.001
L1LGPR-T-L3LGPR-T	-.054	"	NS
L2LGPR-T-L3LGPR-T	-.018	"	NS
L1RSPPR-T-L2RSPPR-T	.223	"	.061
L1RSPPR-T-L3RSPPR-T	.077	"	NS
L2RSPPR-T-L3RSPPR-T	.212	"	.071
L1TOTPR-T-L2TOTPR-T	.426	"	.001
L1TOTPR-T-L3TOTPR-T	.003	"	NS
L2TOTPR-T-L3TOTPR-T	.064	"	NS

L1 = Corridor adjacent to Fracture Room
 L2 = Proctology Room
 L3 = Room 116
 LGPR-T = Large particles: Stages 1-3 ($\geq 5\mu\text{m}$ diameter)
 RSPPR-T = Respirable particles: Stages 4-6 ($\leq 5\mu\text{m}$ diameter)
 TOTPR-T = Total particles : Stages 1-6.

Levels of CFP at the Cast Room location were 4-5 times higher than at other stations at Long Beach, as well as higher than any we had previously noted. At the time, this value represented a "ceiling" level which we believed should not be exceeded as a result of retrofit changes (see p. 10).

Of notable exception to the statement that no significant variations were found in the analysis, was the high numbers of CFP on Stage 5 (only) in a ward room (Room 116). The coefficient of variation, contrasted with Proctology, was 0.42 with a .001 level of significance. Evidently a source of CFP in the 1-2 μm range was coincident with either the location or activity in the room. Since the room was occupied at that time, the most likely source would have been the routine linen-changing activity.

TABLE 3 C

Analysis of variance - Long Beach Naval Hospital

Stage(s)	Source	Mean Square	Degrees of Freedom	F	p value
1+2+3	Location	3512929.01	2	68.08	.001
	Time	24389.48	4	.47	.756
	Location x time	10189.34	8	.19	.991
	Residual	51597.78	276		
	Multiple r ²	.332			
4+5+6	Location	148563.13	2	12.14	.001
	Time	28940.59	4	2.36	.053
	Location x time	6454.37	8	.52	.835
	Residual	12229.67	276		
	Multiple r ²	.10			
TOTAL	Location	5054808.70	2	56.75	.001
	Time	83930.03	4	.94	.440
	Location x time	24092.86	8	.27	.975
	Residual	89072.26	276		
	Multiple r ²	.293			
PPM CO ₂	Location	5559951.47	2	157.31	.001
	Time	14508.74	4	.41	.801
	Location x time	6532.18	8	.18	.993
	Residual	35343.55	276		
	Multiple r ²	.533			

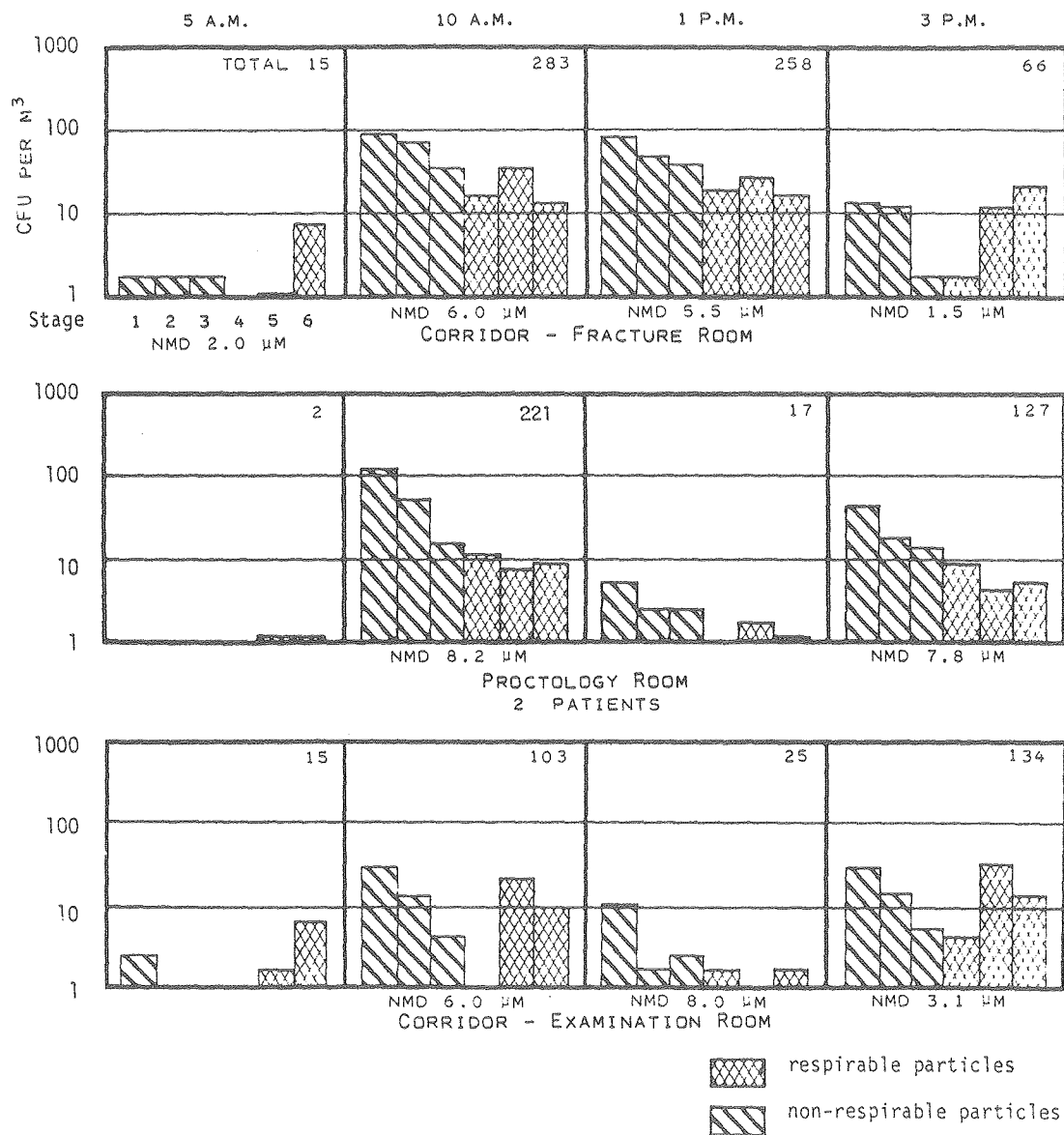


FIG. 2. Particle size distribution (by Andersen stage), CFU per m^3

Long Beach Naval Hospital

5 a.m. - 3 p.m. Sept 18, 1978

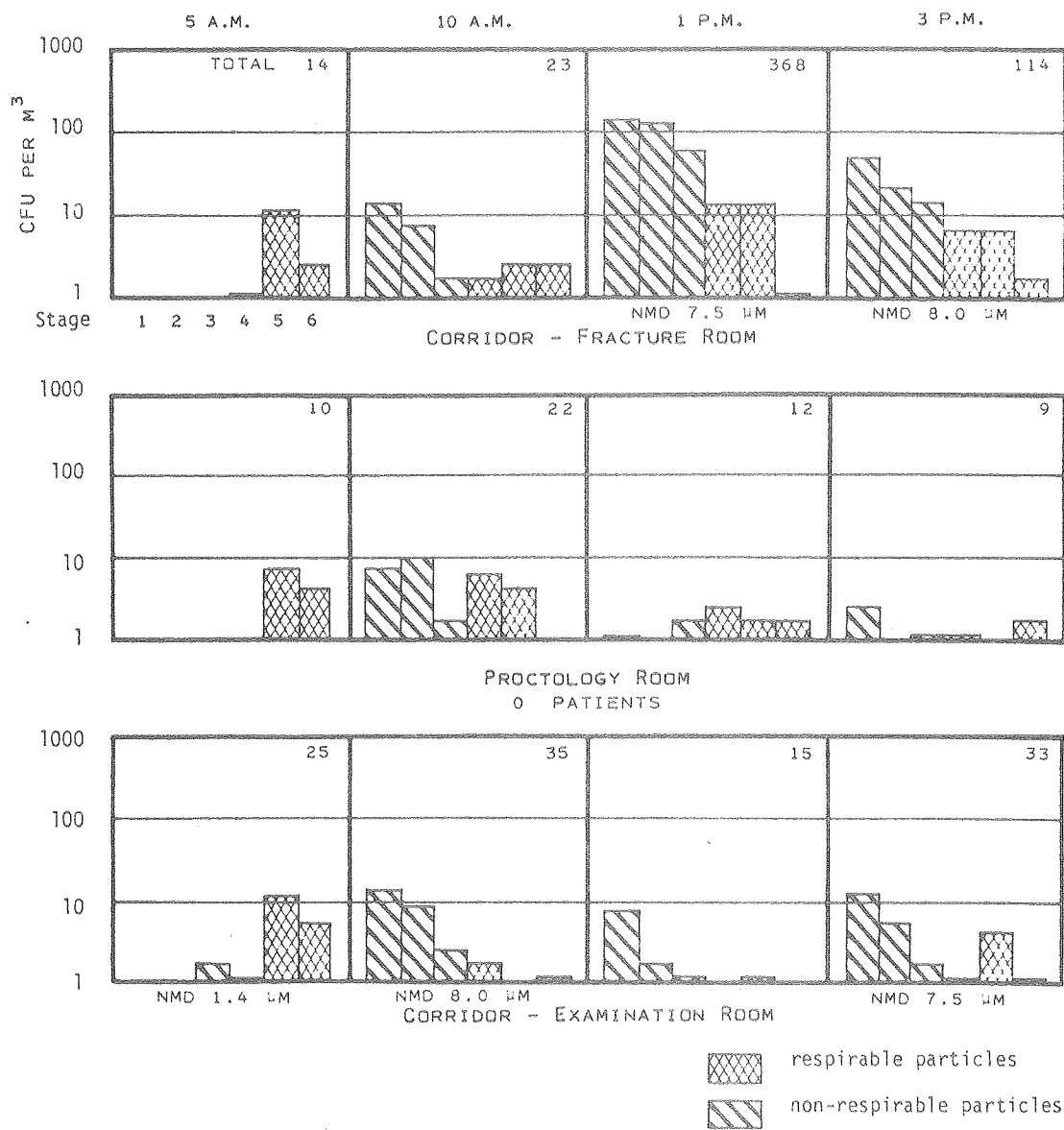


FIG. 3. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital
 5 a.m. - 3 p.m. Sept 19, 1978

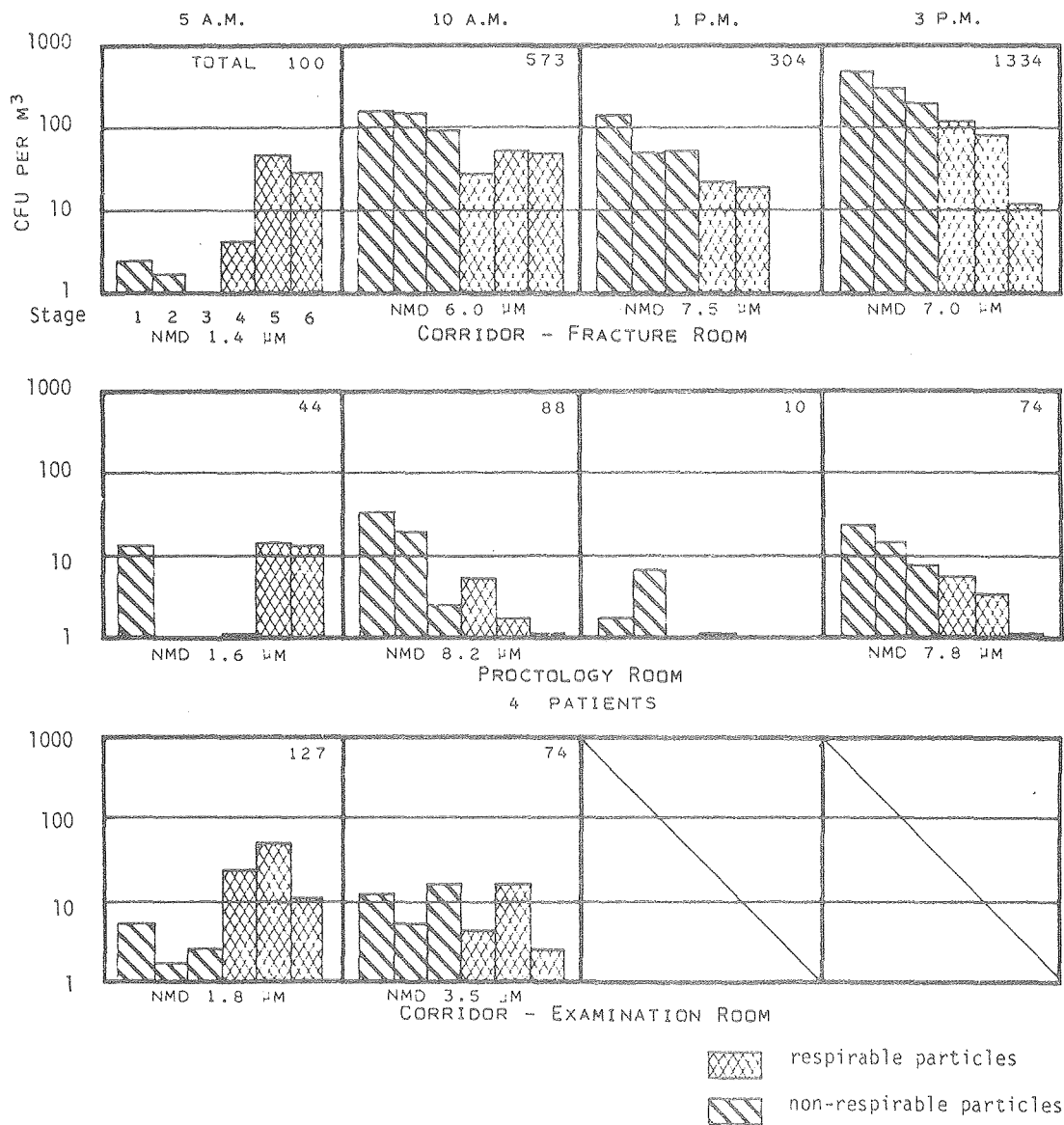


FIG. 4. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m. - 3 p.m. Sept 20, 1978

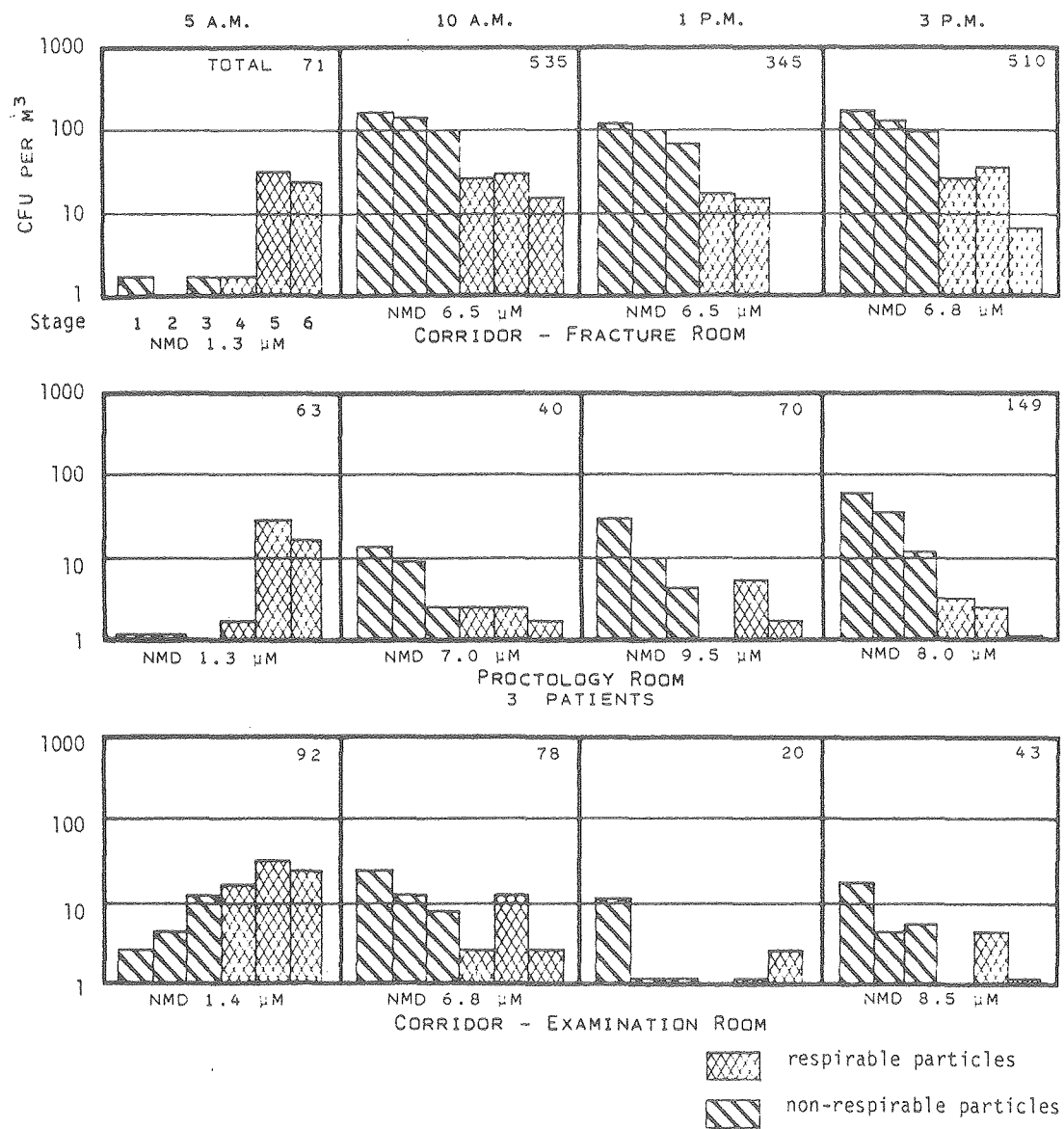


FIG. 5. Particle size distribution (by Andersen stage), CFU per m^3

Long Beach Naval Hospital

5 a.m. - 3 p.m. Sept 21, 1978

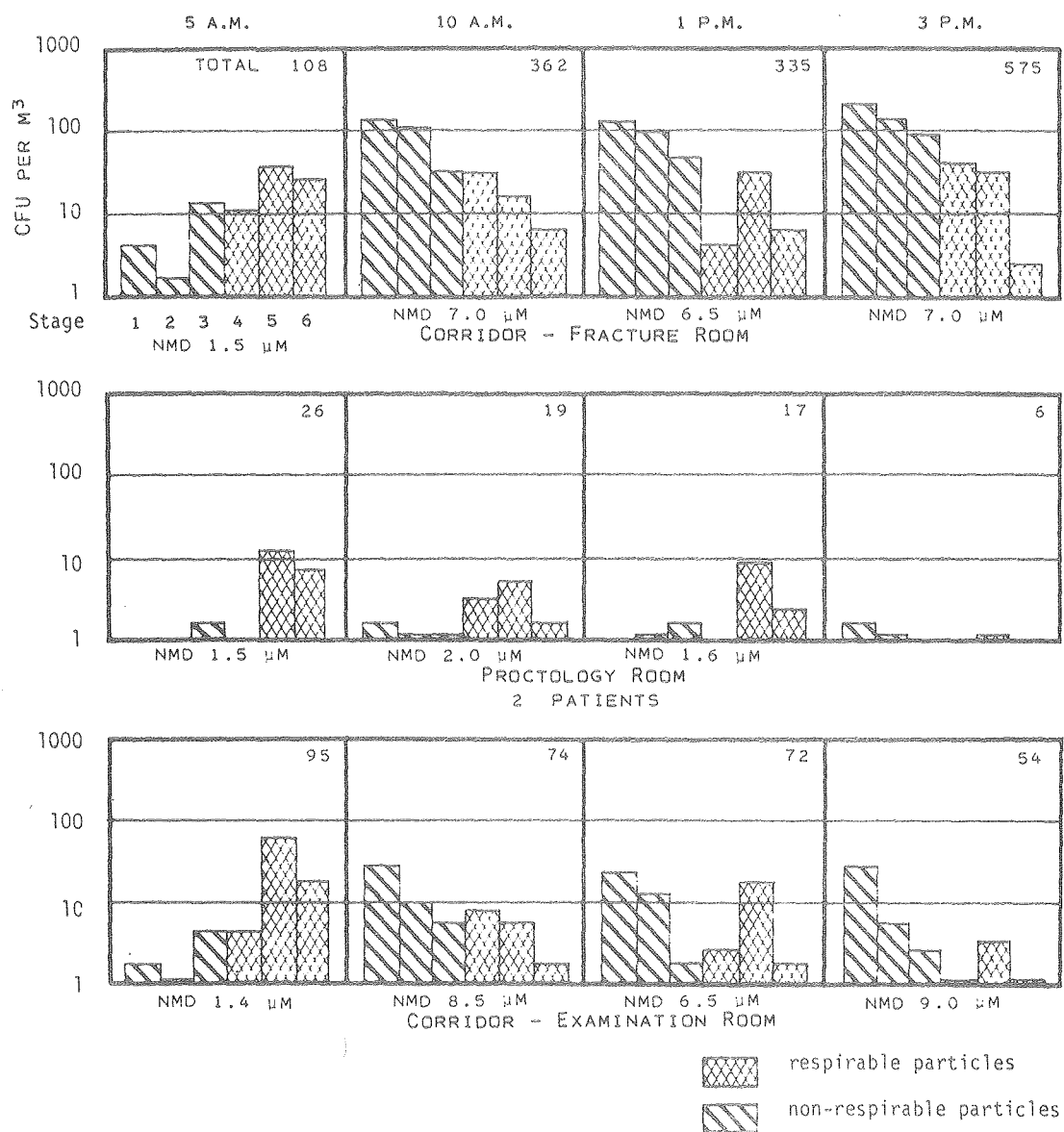


FIG. 6. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m. - 3 p.m. Sept 22, 1978

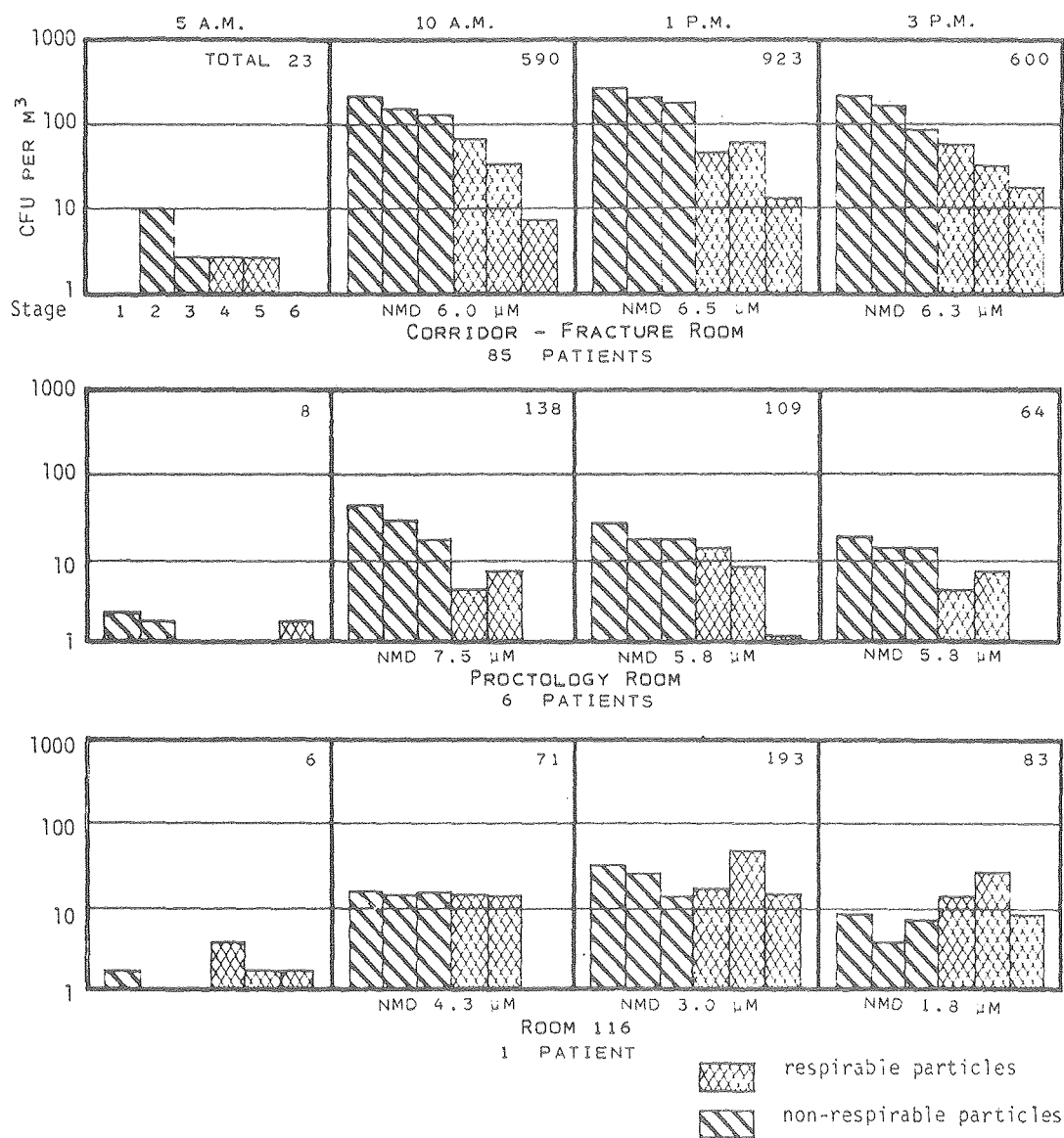


FIG. 7. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m.-3 p.m. Oct. 16, 1978

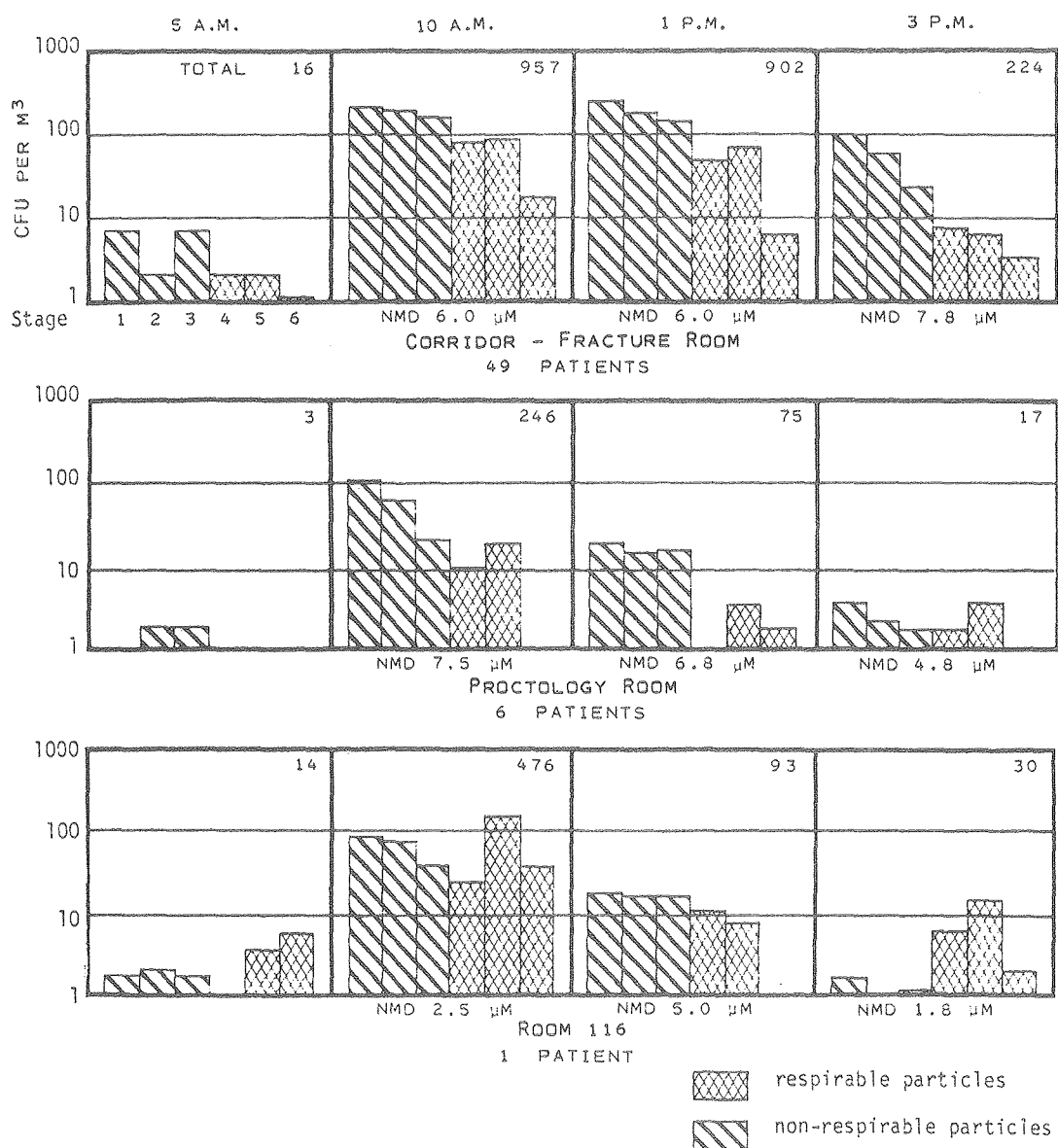


FIG. 8. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m.- 3 p.m. Oct. 17, 1978

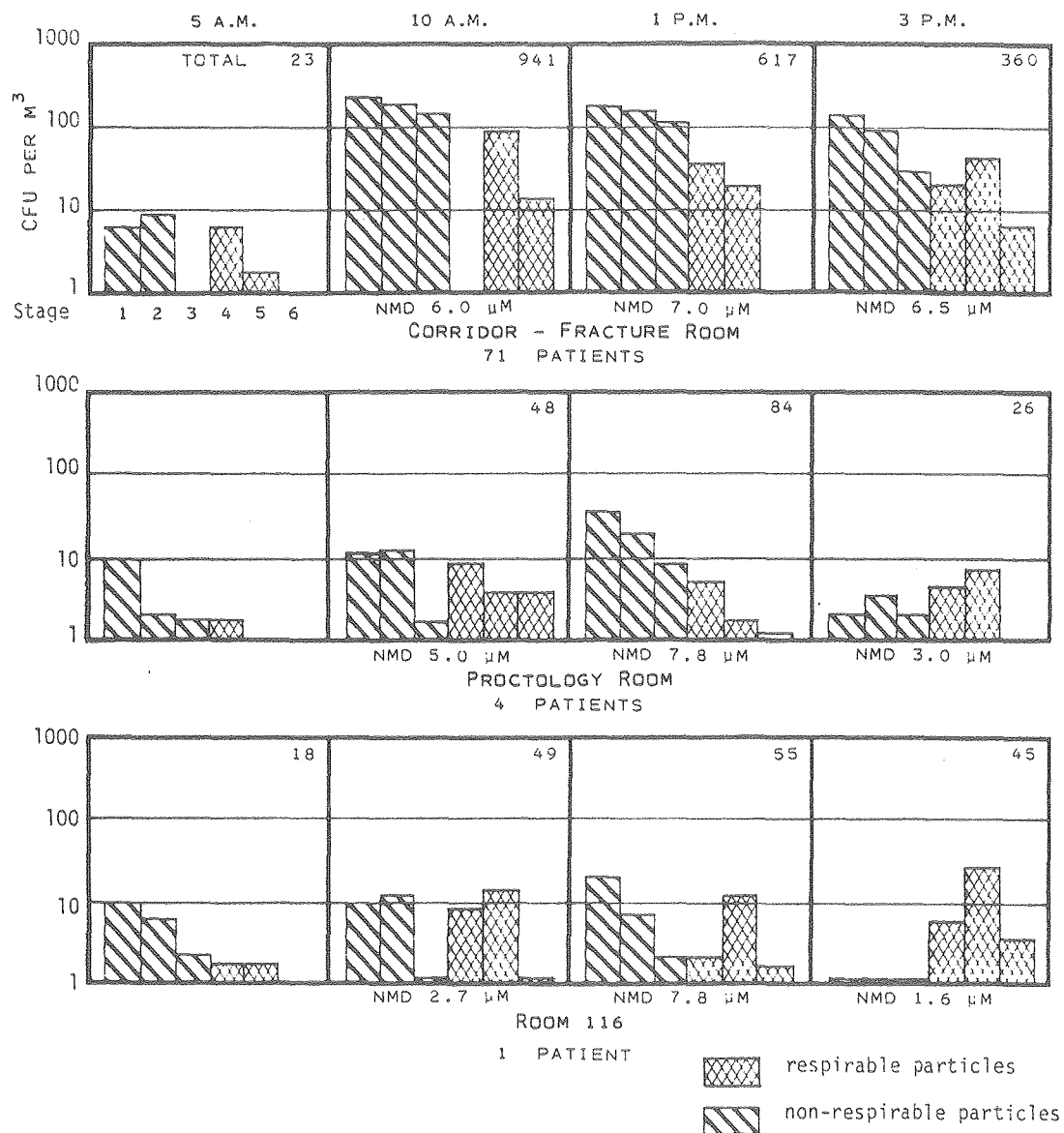


FIG. 9. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m.- 3 p.m. Oct. 18, 1978

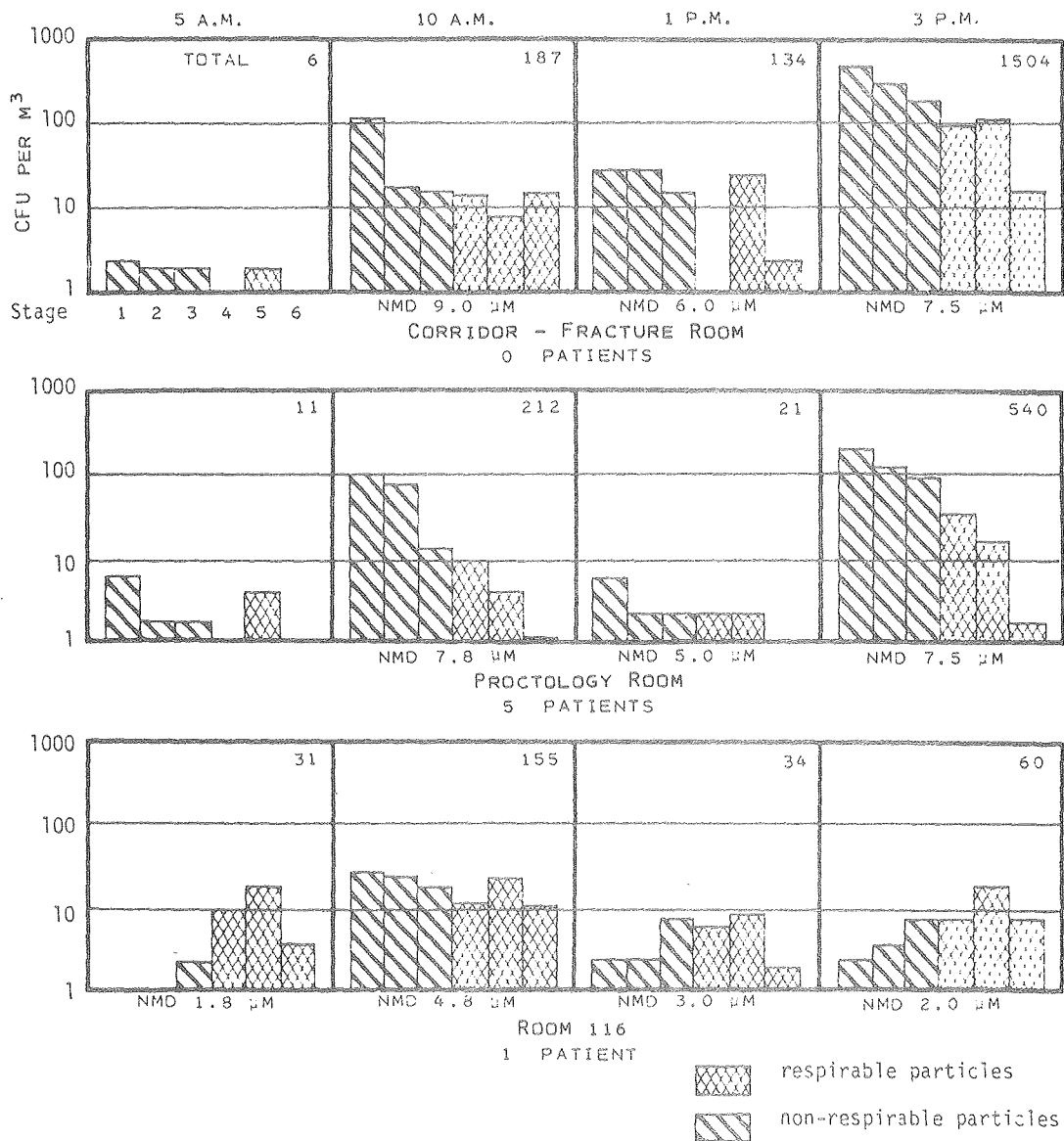


FIG. 10. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m.- 3 p.m. Oct. 19, 1978

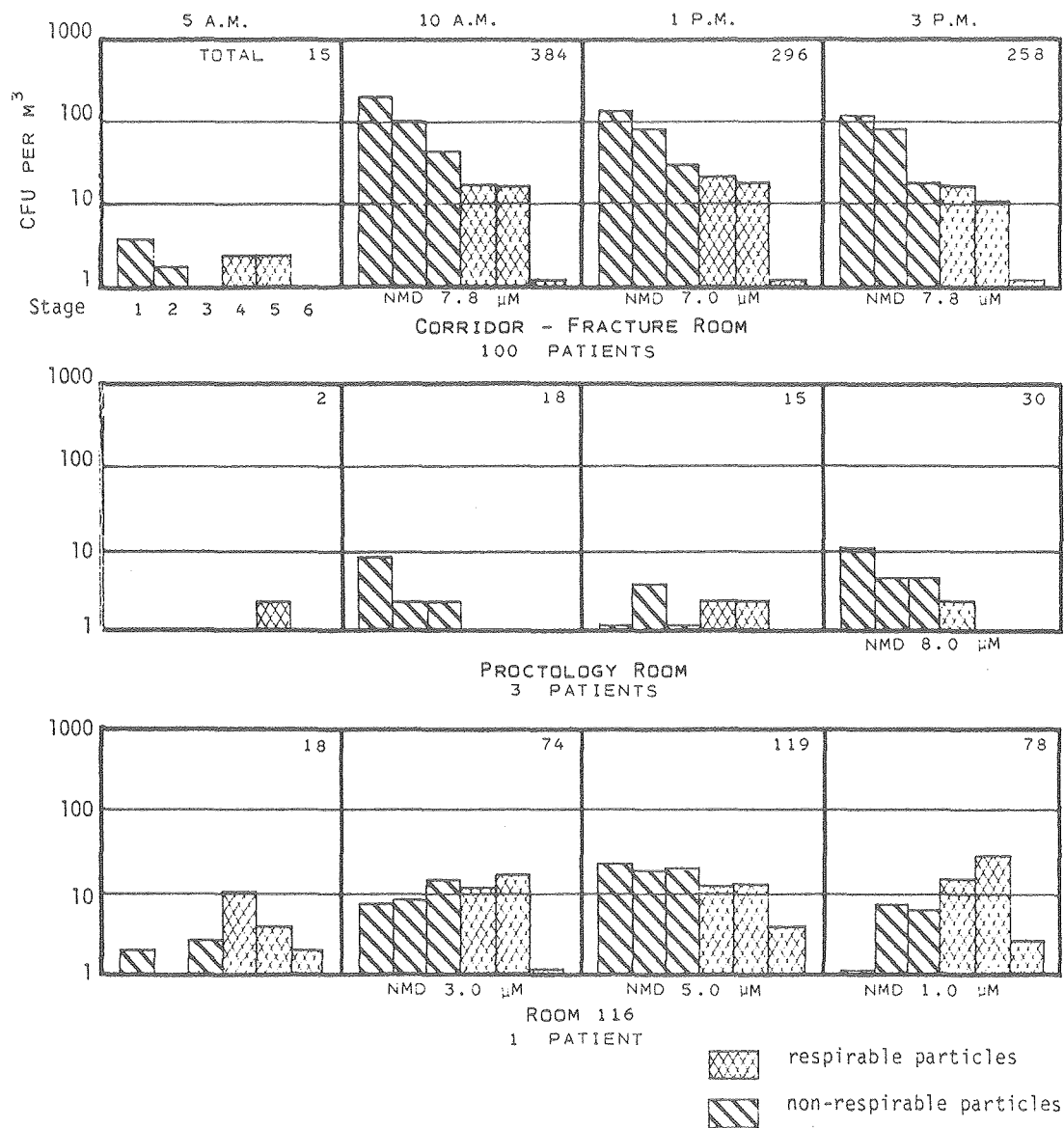


FIG. 11. Particle size distribution (by Andersen stage), CFU per m³

Long Beach Naval Hospital

5 a.m.- 3 p.m. Oct. 20, 1978

3. Analysis of total particles

During the initial sampling at Long Beach (1978), a particle monitor (Royco, Model 225, 6 size ranges) was used in a continuous mode to provide an estimate of the numbers of particles present in the air near (as practicable) the biological sampler at the Cast Room location. Raw data were recorded on disk or tape, and became available for analysis during the late spring of 1979. Data from channels 1(smallest particles) and 6 (largest particles) were not analyzed because of noise (channel 1) and too few counts to be significant (channel 6).

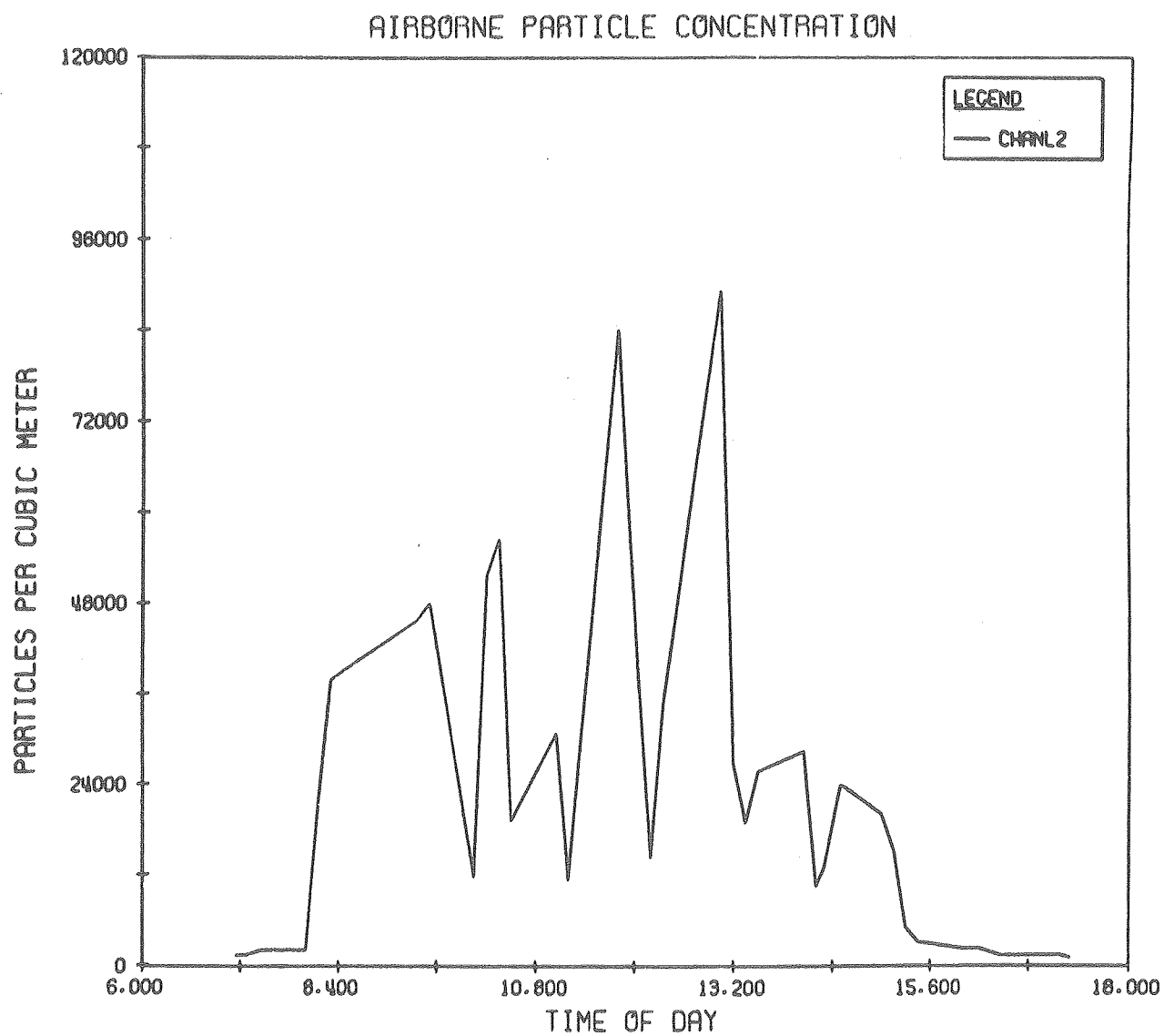
The sampler draws air through the vertical image of a slit illuminated with a high-intensity lamp. Light scattered in a forward direction is detected by a photocell. The pulse output is amplified, shaped and applied to a multi-channel, pulse-height analyzer.

A theoretically perfect, spherical particle with 100 percent reflectance, scatters light in a complex but known manner. If the integrated intensity is measured over a large angle, the intensity of the scattered light can be related to particle size. Naturally-formed particles are seldom spherical and vary in reflectance. Hence, the data should be interpreted as "the observed size distributions of samples are those of a perfect aerosol having these apparent properties." The situation is similar to that of the sizing of particles by cascade impactors (e.g., Andersen Samplers) in that a sampled aerosol appeared to have aerodynamic-size properties associated with a perfect aerosol of the observed distribution. Because of shape and density factors, the size may not have had that distribution if collected particles had been sized by optical methods.

Figure 12 shows a typical, computer-generated, example of how the particle numbers counted by one channel of the RoyCo analyzer varied during a day. Obviously, the varied activities produced more or less momentary bursts of particles that decreased rapidly because of settling, diffusion and air movement. A graph such as this is not very meaningful.

We modified these graphs, subjectively, by hand-drawn, smooth curves from raw data. These are shown in Figures 13 through 17, and reveal a general tendency for activity at the hospital to have been relatively periodic. With one exception all major peaks occurred within the times 9:00 a.m. to 10:20 a.m., 12:30 p.m. to 1:30 p.m., and 3:00 p.m. to 4:10 p.m. Note that the lines representing the temporal changes of particle numbers counted per channel remain relatively parallel, indicating only trivial changes in particle size distribution occurred from sample to sample.

Fig. 18 shows the size distribution of the particulate matter near the Cast Room contrasted to the distribution of the CFP also associated with the Cast Room. Both are essentially log-normal, but the deviation of the CFP is wider than that of total particles; bacteria are found more frequently on or within larger particles than in smaller particles. This is not an unexpected finding, because the probability of having at least one viable microbe per particle is related to the volume of the particle.



CHANGES IN AIRBORNE PARTICLE CONCENTRATION WITH TIME
Cast Room, Long Beach Naval Hospital

FIG. 12.

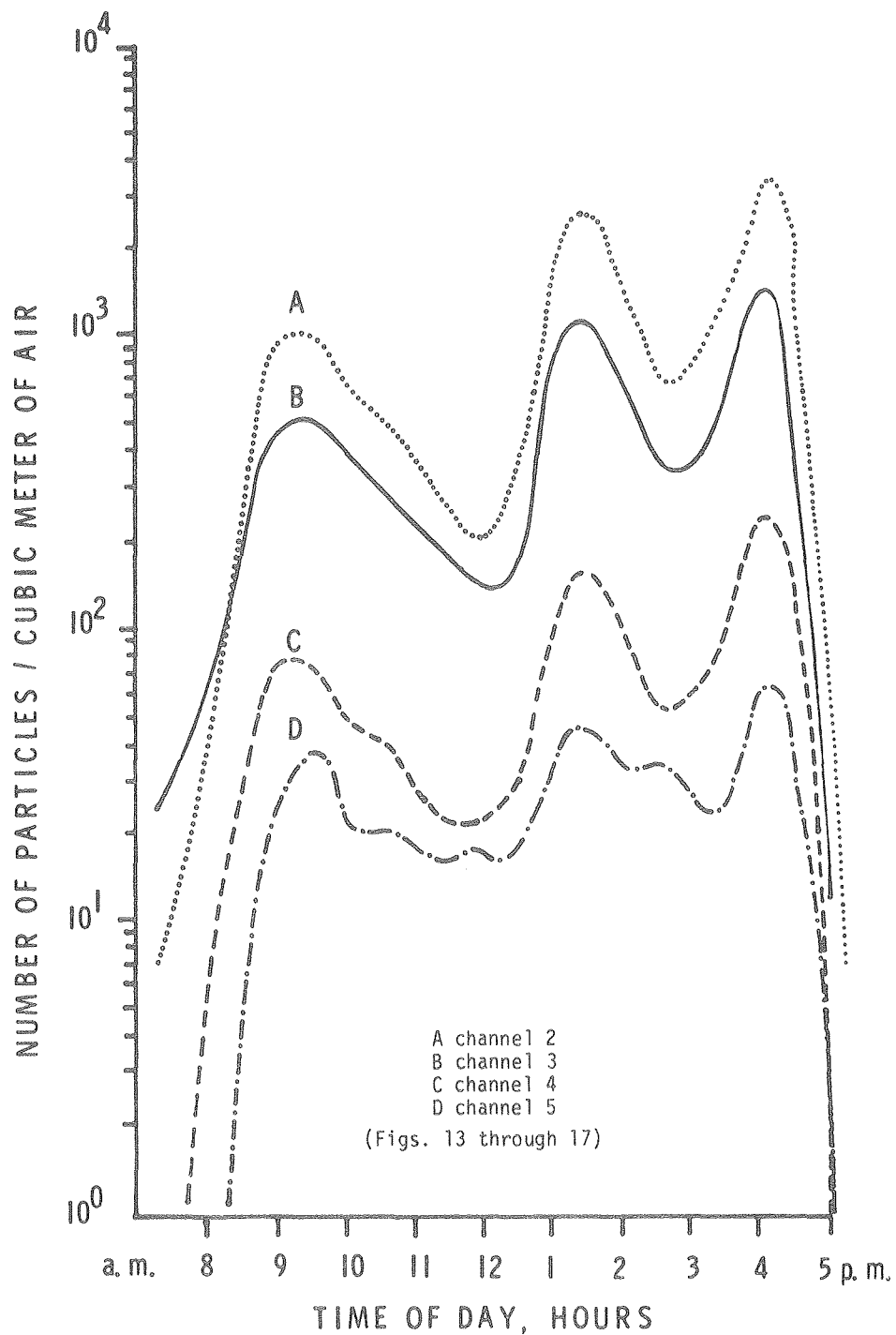


FIG. 13. VARIATION OF THE NUMBER OF PARTICLES IN AIR OF CORRIDOR OUTSIDE ORTHOPEDIC CAST ROOM, LONGBEACH NAVAL HOSPITAL, (10/16/78).

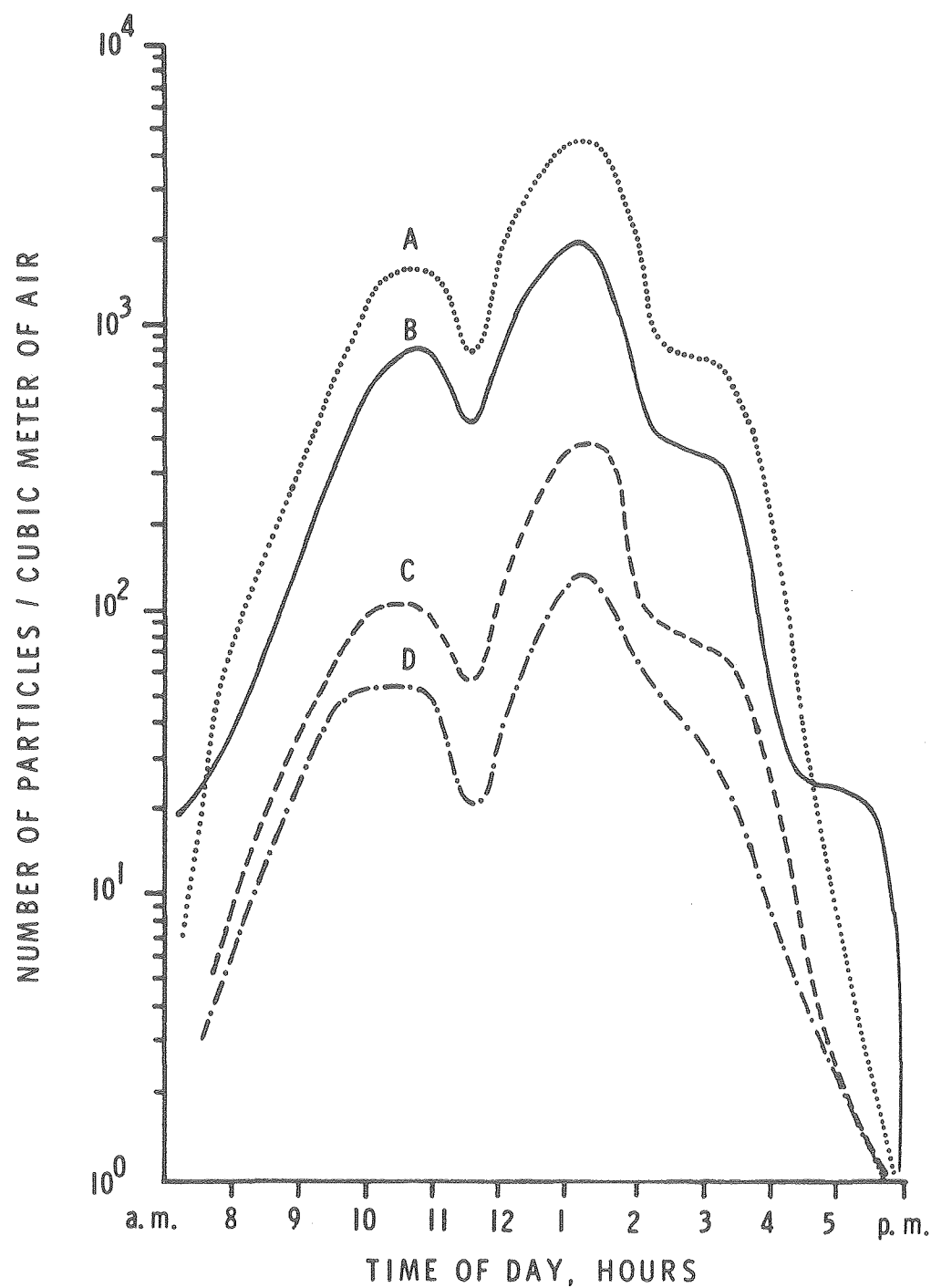


FIG. 14.

VARIATION OF THE NUMBER OF PARTICLES IN AIR OF CORRIDOR OUTSIDE ORTHOPEDIC CAST ROOM, LONGBEACH NAVAL HOSPITAL, (10/17/78).

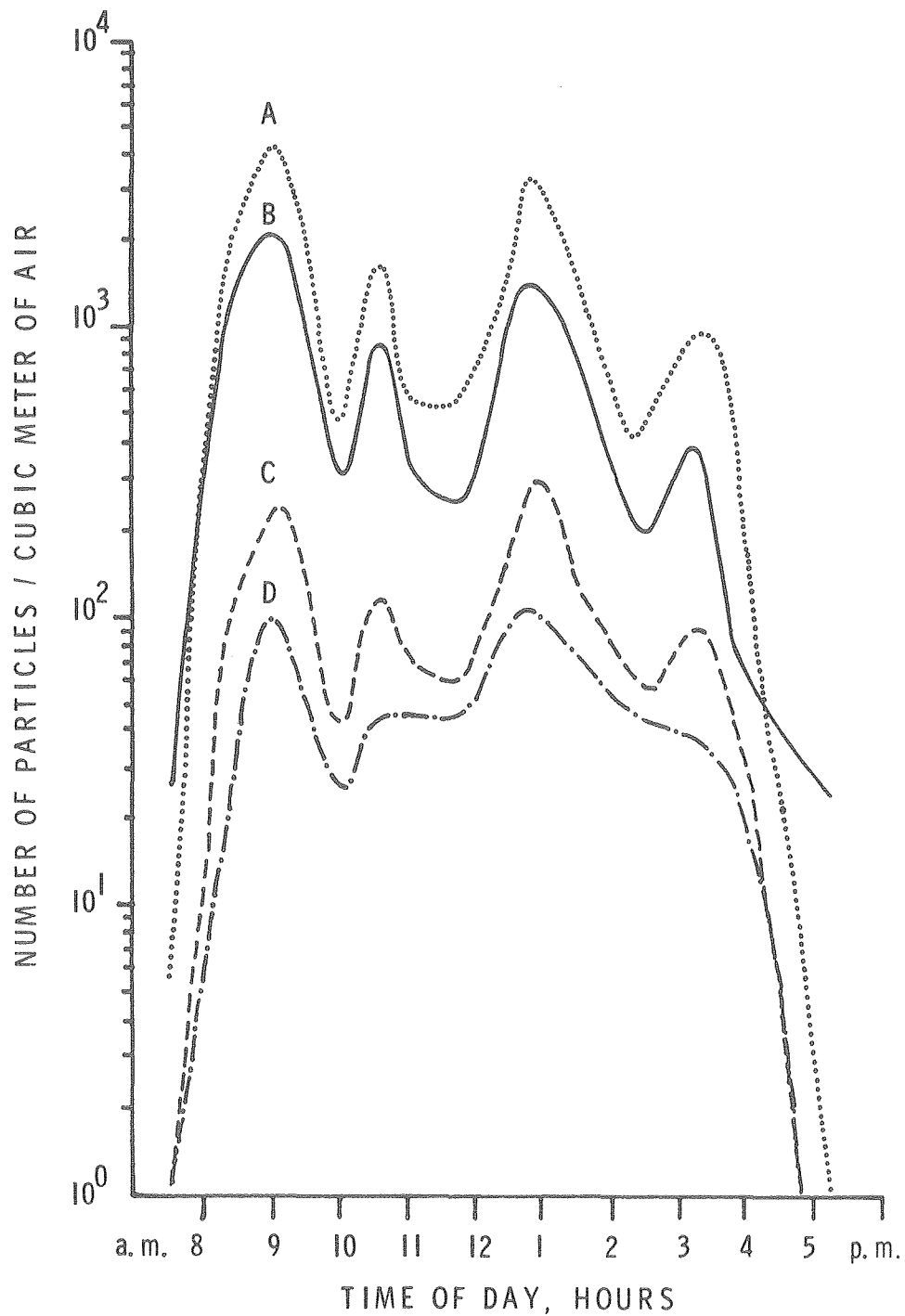


FIG. 15. VARIATION OF THE NUMBER OF PARTICLES IN AIR OF CORRIDOR OUTSIDE ORTHODPedic CAST ROOM, LONGBEACH NAVAL HOSPITAL, (10/18/78).

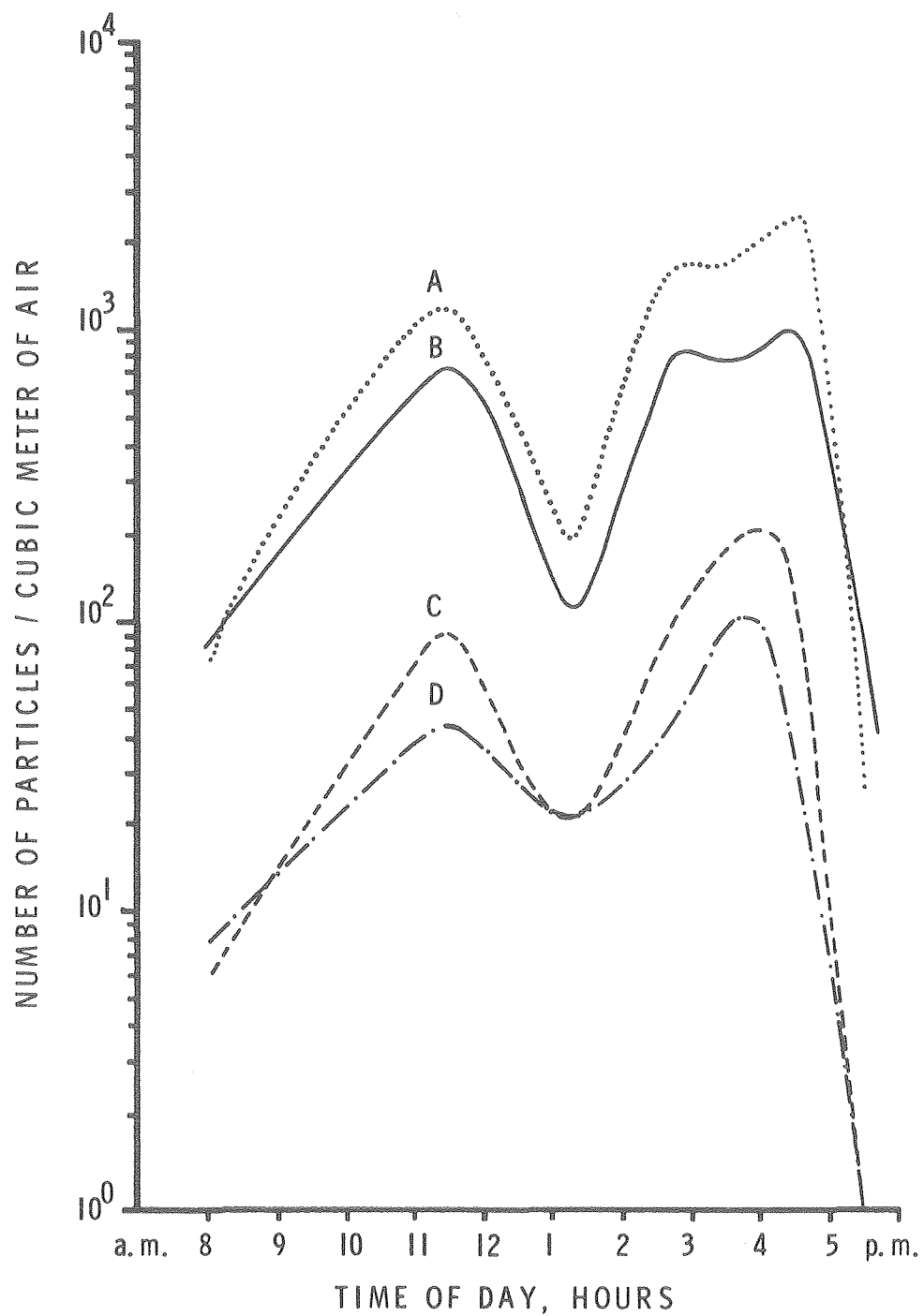


FIG. 16. VARIATION OF THE NUMBER OF PARTICLES IN AIR OF CORRIDOR OUTSIDE ORTHOPEDIC CAST ROOM, LONGBEACH NAVAL HOSPITAL, (10/19/78).

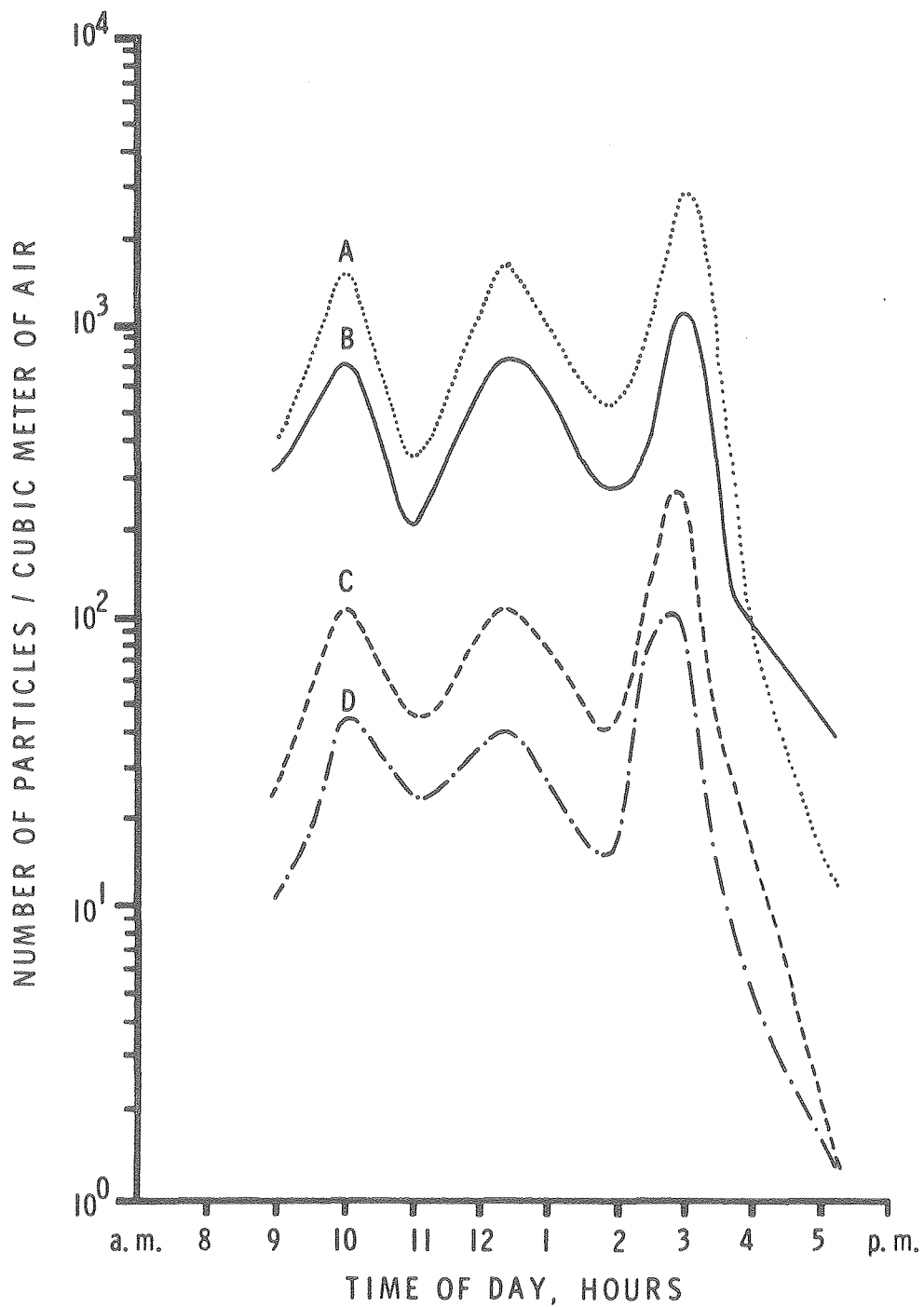
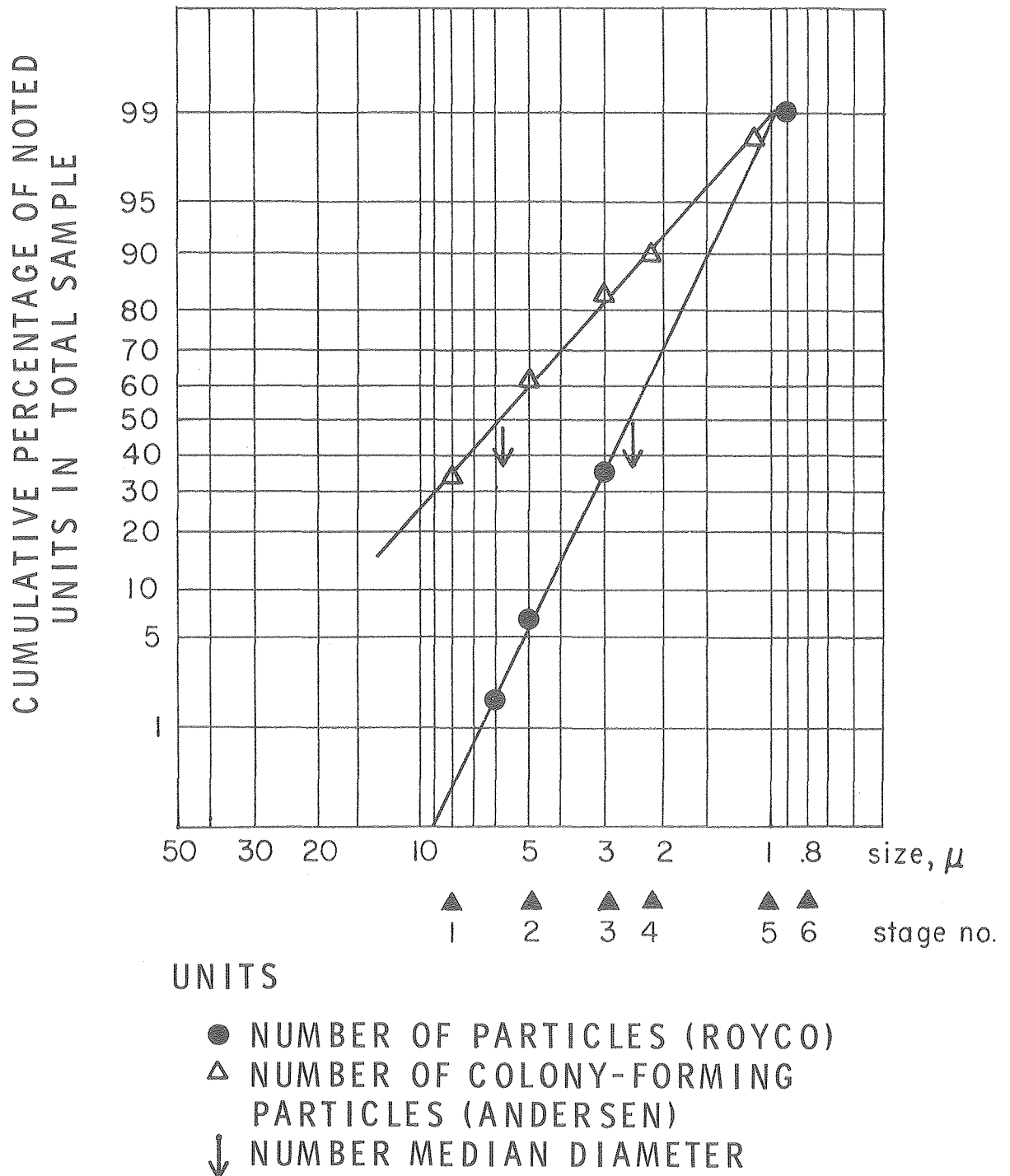


FIG. 17. VARIATION OF THE NUMBER OF PARTICLES IN AIR OF CORRIDOR OUTSIDE ORTHOPEDIC CAST ROOM, LONGBEACH NAVAL HOSPITAL, (10/20/78).

LONGBEACH HOSPITAL - CAST ROOM

FIG. 18. COMPARISON OF SIZE DISTRIBUTION OF TOTAL PARTICLES TO THOSE CONTAINING VIABLE BACTERIA.



E. LONG BEACH NAVAL HOSPITAL STUDIES IN 1979

Three on-site tests were made at Long Beach Naval Hospital during 1979. The first, mentioned above, was intended to recapitulate sampling at sites where data had indicated the presence of unexpected situations during 1978; the second was to provide comparative data in preparation for changes in protocol and the third was in response to a new sampling protocol.

1. Differential media tests

Because the number of CFP found in air associated with the Cast Room was about 4 times that found in other sites that had been sampled, we felt that a more selective survey was required to characterize the nature of the microflora. Although we had not intended to use media that would support growth of a given genus (selective media) because of the possibility of introducing bias into data collected before and after retrofit, and for reasons involving cost, we decided to do so in this instance, for the purpose of contrasting these data with results obtained in another location. In addition, we were interested in testing whether tri-plates (plastic Petri dishes molded with three, equal, pie-shaped sections) would collect airborne bacteria with the same efficiency as standard plates. If so, this would provide a less expensive way to use differential media than collecting a separate sample for each type.

As an initial test, air from an artificially created aerosol and air from a Men's rest room were sampled using standard plates with the standard media (TSA agar), with tri-plates using TSA in all sections and with TSA in one section only. In the latter case, obviously, the number of colonies counted was multiplied by 3 for comparative purposes.

Tests with the aerosol indicated that the tri-plates would be satisfactory. Variation within tri-plate samples was ± 5 percent and between the tri-plate and standard plate it was also ± 5 percent. With few exceptions, all colonies were found on stages 4, 5 and 6, which is where they should have been, since the aerosol was generated in the particle size range of 1-3 μm . One aerosol was created from a high number of bacteria, and with an increased solids content to produce larger particles and higher counts. The intent was to reduce the effects of experimental variation common to small numbers, and to do this on all stages. The total number of colonies found on tri-plates was 3650 and on standard plates, 3749, an insignificant difference.

TSA-filled tri-plates and TSA-filled standard plates were used to sample air in a local Men's Room. The mean ratio of TSA-plate/Tri-plate, as CFP, was 1.11 ($n = 14$). Thus, tri-plates are about 90 percent efficient, when compared to standard Petri plates. This difference is trivial when contrasted to the variation of CFP shown to exist in "normal" room air, even when samples are taken simultaneously and one sampler spaced as close to the other as possible. The use of tri-plates rather than multiple sampling, therefore, represents an inexpensive method of assaying airborne microflora for generic content. Field sampling thereafter (May through October) utilized tri-plates (see 2, below).

2. Supplemental sampling near Cast Room and adjoining areas.

Two sampling units were taken to Long Beach Naval Hospital. Samplers were supplied with tri-plates containing TSA (standard agar), Mannitol Salts Agar (presumptively selective for the *Staphylococcus* genus) and Pseudosei Agar (selective for the *Pseudomonas* genus). Colonies that grew on Mannitol agar were transferred to (TSA + DNA) agar. After colonies appeared, the plates were flooded with 1N HCl which coagulates DNA. Clear areas indicated colonies that were capable of destroying DNA and were considered to be *Staphylococcus aureus*.

A brief field-test was conducted at the Long Beach Naval Hospital, using the tri-plates and 2 sample-sites; the corridor outside the Cast Room (site 1) and a nearby corridor outside the Obstetrics room (site 2). Coincidentally, a reduction in the Orthopedics staff had occurred and the work-load of the Cast Room had decreased, a situation we had not known prior to that visit.

The mean number of CFP at site 1 was $229/\text{m}^3$ (S.D.=125); the mean number at site 2 was $38 \text{ CFP}/\text{m}^3$ (S.D.=138). The decreased work load was reflected in a decreased number of CFP at this time, 229 contrasted to about $400 \text{ CFP}/\text{m}^3$ found previously.

There were no pseudomonad species detected in the air of the hospital. Forty-four colonies that were positive for *S. aureus* were detected in air associated with the Cast Room; 7 were positive in air of the other corridor. The ratio of 44/229 is 0.19 and the ratio of 7/38 is 0.18; we interpret this similarity to indicate that the predominant flora in air outside the Obstetrics Clinic came principally from the Cast Room but was diluted about 6-fold. There were too few staphylococci, however, to provide data adequate for particle size analysis.

3. Final Visit to Long Beach Site

This visit was conducted in July as a preliminary study for the changed protocol, designed to accommodate the closing of the Cast Room by providing other potential field-monitoring locations within Long Beach Naval Hospital. We wanted to obtain data from prior and new locations, simultaneously, for comparative purposes.

Four locales were used: (a) The Waiting Room at the Pediatrics Clinic; (b) the corridor outside Obstetrics-Gynecology; (c) the corridor outside the Cast Room, and (d) the corridor outside the Eye Surgery operatory.

(a) Pediatrics

The mean of two-week's sampling was $183 \text{ CFP}/\text{m}^3$ (S.D.=139). No pseudomonad types were found. Two colonies in all samples were positive for *S. aureus* sp. There appeared to be a significant, time-dependent trend, highest at 9:00 a.m. ($219 \text{ CFP}/\text{m}^3$), lowest at 4:00 p.m. ($126 \text{ CFP}/\text{m}^3$).

(b) Obstetrics

The mean at this locale was 125 CFP/m³ (S.D.=143). No pseudomonad types were found. Eleven colonies were positive for S. aureus sp. There was a significant time-dependent trend, highest at 9:00 a.m. (187 CFP/m³) and lowest at 4:00 p.m. (67 CFP/m³).

(c) Cast Room

The mean at this locale was 343 CFP/m³ (S.D.=278). No pseudomonad types were found. Nine colonies were positive for S. aureus sp. At this locale there appeared to be no significant, time-dependent trend.

(d) Surgery

The mean at this locale was 85 CFP/m³ (S.D.=89). No pseudomonad types were found. Four colonies were positive for S. aureus sp. There was a significant time-dependent trend, highest at 9:00 a.m. (114 CFP/m³) and lowest at 4:00 p.m. (59 CFP/m³).

These time-trends are interesting in that we had never observed similar trends in prior sampling, and in that they neither correspond to the peak activity periods noted on pg 24, nor the correlation analysis of 1978 data, Sec. D-1.

The general level of bioburden during this last sampling effort was about the same as observed in other habitats.

F. SAMPLING AT SOCIAL SERVICES BUILDING, SAN FRANCISCO

This site, a substitute for the Long Beach retrofit study, was selected by the LBL team as being easy to access, nearby, and was typical of public buildings that might be included in future energy-saving procedures.

Two locales were sampled; a waiting room and an adjoining "interview" room. The two conditions tested were normal ventilation and reduced ventilation. A three-day initial sampling was done, then a one-week period of reduced ventilation, and finally another one-week period of normal ventilation. Four sampling intervals per day had been planned, but some were missed because of traffic delays, and some because the samplers had been tampered with.

The total number of samples (50 per locale) was too few to allow a formal correlation analysis. Fortunately, such was not necessary (with respect to retrofit) and this site visit provided us with data more applicable to analysis of effects of retrofit than any previously obtained.

Additional sampling was done with the RoyCo particle sampler and with a slit sampler located on the roof of the building.

Table 4 summarizes the biological data.

TABLE 4

Mean values of CFP/m³ found in air
Social Welfare Building, San Francisco, Ca.

	<u>Waiting Room</u>	<u>Office</u>
Normal Ventilation (20-33 cfm/person)	105	56
Reduced Ventilation (4-6 cfm/person)	179	58
	t = 4.14	(No significant difference)

(difference is significant at better than
the 0.001 probability level)

The difference between normal and reduced ventilation is highly significant, but only in the waiting room. This difference between the two rooms is probably a result of considerably less activity in the office space, and fewer persons within the room. There was no obvious evidence of a time-dependent trend.

Samples of air were obtained in the waiting room by means of the RoyCo particle-size analyzer.

Table 5 summarizes the particulate data.

TABLE 5

Number of particles/m³ found in air
Social Welfare Bldg., San Francisco

	<u>CHANNEL NUMBER</u>			
	2 (1μm)	3 (3 μm)	4 (5μm)	5 (>6μm)
Normal Ventilation	700 (24734/m ³)	848 (29964/m ³)	45 (1590/m ³)	30 (1060/m ³)
Reduced Ventilation	1712 (60494/m ³)	1406 (49682/m ³)	64 (2261/m ³)	45 (1590/m ³)
	t = 2.86	t = 2.32	(No significant diff.)	

(The differences are significant
at the 0.05 probability level)

The difference between the particulate level for small particles, before and after reduction of ventilation rate is not as great as that of the CFP, but it does indicate that the clearance rate had decreased when ventilation decreased. The fact that only smaller particles had responded to the decreased ventilation prompted us to re-examine the biological data.

The mean of the CFP collected (per sampling period of 20 mins) from all samples in the waiting room on stages 1,2,3 (larger particles) was 29.8 before retrofit and 42.9 after; the t-score was 2.90, which is significant at the 0.001 probability level. The mean of the CFP collected from all samples in the waiting room on stages 4,5,6 (smaller particles) was 9.05 before retrofit and 23.5 after; the t-score was 4.17, which is highly significant, and 1/3 larger than the other t-score. Evidently, small CFP are a better index of effects of reduced ventilation than larger particles.

One explanation is that larger particles are removed more readily in ducts, and by impaction on fan blades and coarse filters, than smaller particles. Hence, unless the recirculation rate is reduced to very low levels, no increased efficiency of impaction of smaller particles occurs, but the efficiency of impaction of larger particles is increased, perhaps enough to compensate for the decreased dilution effect of the decreased outside air intake. If there is a continuous source of the smaller particles resulting from human activity, then the number of smaller particles will increase. The smaller particles did not arise from outside air because the control samples (5:00 a.m.) showed a level of less than 10 CFP/m³, hence, the activities of people in the waiting room must have been the source.

These data seem to contradict the results from the in-house tests of clearance rates (See pgs. 2 - 5). Those studies, however, were of clearance rates and not for potential build-up of particles; a continuous particle source for the two sizes was not used because of the difficulty of maintaining a constant ratio of particulate output, without which the data would have been biased.

Another explanation is that, considering the variance of the two particle size ranges contrasted to means, there were too few large size CFP to reflect a significant difference as a result of reduced ventilation.

Some ancillary findings in this study were:

(a) There were a few DNA-ase positive staphylococci found in the air of the waiting room, but their appearance was sporadic.

(b) Sampling on the roof at night revealed that there were less than 20 CFP/m³ (note, again, that the slit sampler is not a quantitative device), mostly fungi; no Pseudomonads or staphylococci genera were found. The high ratio of fungi is probably caused by the generally high humidity (fog) in San Francisco. There was no evidence that outside air influenced the effects noted as a result of reduced ventilation.

G. SAMPLING NEAR A CAST ROOM AT THE VETERAN'S HOSPITAL
MARTINEZ, CALIFORNIA

The high numbers of CFP found in air near the Cast Room at Long Beach posed a question of whether that situation was typical of Cast Rooms in general. We sampled air near the Cast Room and in a Conference Room (as a background control) at the Veteran's Hospital at Martinez.

For the cast room, we found a mean value of 333 CFP/m³, and the numbers varied from a low value of 100 CFP/m³ to a high of 1312 CFP/m³. The numbers are not significantly different from those CFP found at Long Beach. The highest value was found during a day when patient load was high, was the only sample having DNA-ase positive colonies, and those were present only to the extent of 1%. The size distribution was the same as the distribution at Long Beach.

The conference room air, when occupied, contained a mean value of 100 CFP/m³, had no pseudomonad species and no DNA-ase positive colonies, a content similar to other spaces of the same nature.

We believe that these results indicate that the situation observed in air outside the Cast Room at Long Beach is not unique.

H. SAMPLING IN A MEN'S RESTROOM.

Page 32, above, documents the purpose for, and lists some data from a Men's restroom at NBL. This section describes data from that test not related to that section.

We had chosen a Men's room because of the well-known principle that splashing or bubbling produced aerosols from aqueous solutions, and we assumed that we would find a high level of CFP in that room. Two sample units were used, one on each side of the room, about 12 ft apart. The units were set to sample simultaneously. Ventilation was provided by a single, 10-inch window fan.

We found the mean number of CFP to be 135 /m³. The number varied from as low as 12 CFP/m³ to as high as 466 CFP/m³. We determined the ratio for each "duplicate" sample from the two sites. The mean of the ratios was 1.05 with a 95% confidence interval of 1.3 to 0.7. We interpret this to mean that duplicate samples from two sites agreed remarkably well considering the type of ventilation used in the room.

After plates were incubated for 72 hrs small fungal colonies appeared on the surface. Typically, fungi tend to over-grow the plates and are not easily counted, especially if numerous; the sample is essentially worthless. In this instance they were easily enumerated. The mean value of the colony-forming-fungi was 120/m³.

FIG. 19. MEN'S ROOM - NBL
COMPARISON OF SIZE DISTRIBUTION,
BACTERIA AND FUNGI

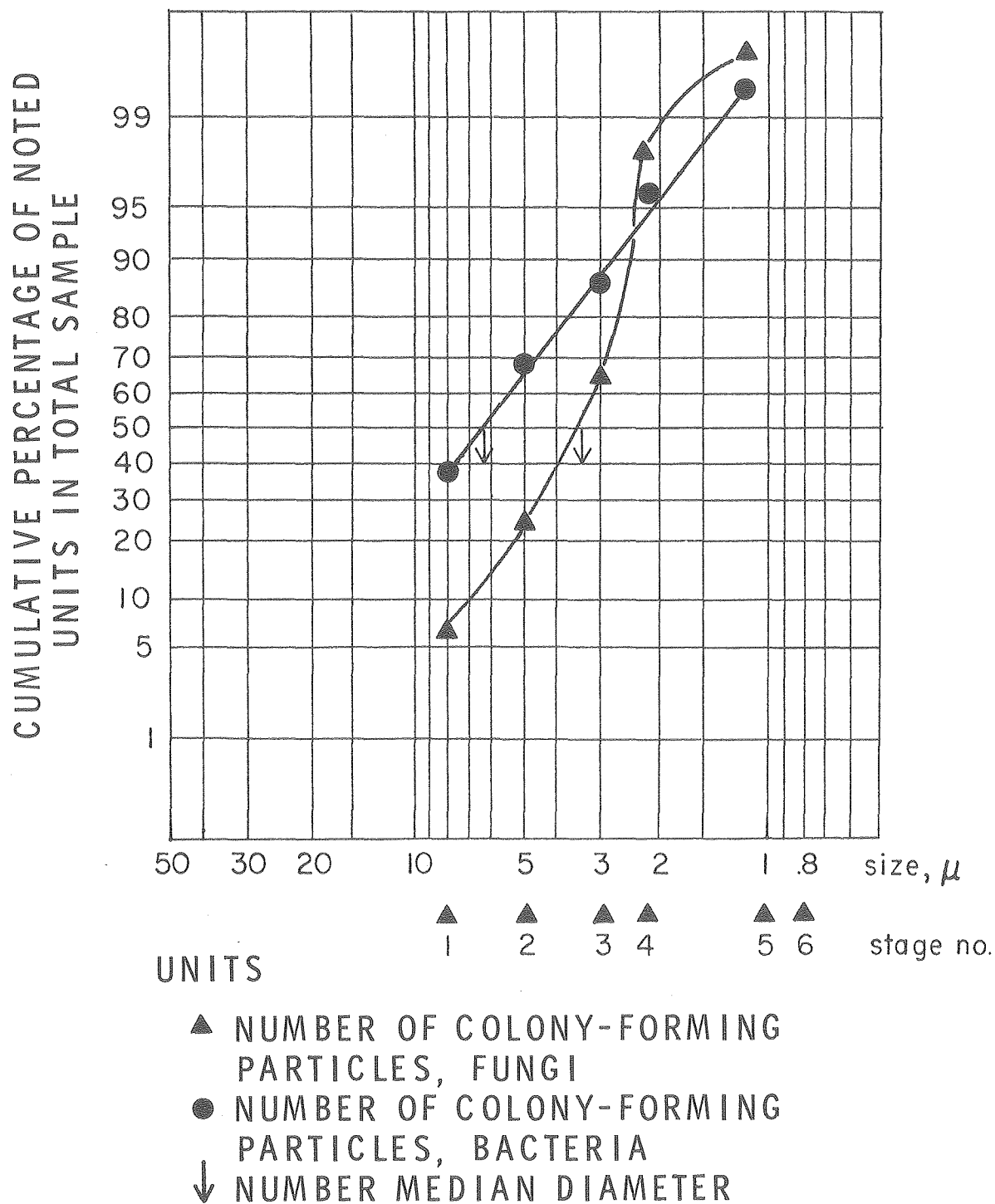


Fig. 19 shows the size distribution of bacteria and fungi collected simultaneously. The fungal spores were in particles 2-5 μm in diameter, whereas the bacteria were associated with particles having a distinctly wider range (1 μm to > 9 μm). Fungi usually produce spores 2 μm - 4 μm in diameter (depending on the species) in grape-like clusters held on "stalks". When the spores are dry, they are readily dispersed by small drafts of air. Therefore, airborne fungal spores are expected to have a rather narrow range of size distribution, although some may occur as doublets, triplets, etc.

This finding corresponds with the above expectations: the number median diameter (NMD) was 3.3 μm , and some clusters were evident as larger particles. It is an effective demonstration of the Andersen, cascade sampler to provide information concerning particle size, and serves to increase confidence in data so collected. We suspect, without proof, that the source of the fungi was in the overhead space that is separated from the room by acoustical tile. There had been a leak in the roof above this room about 3 years prior to the sampling. No special air intake is provided for the room, and measurements of air velocity showed that some air was being drawn into the room via the loosely fitting tile.

This situation is unique to the sampling we have done, and those involved in any future field sampling should be alert to the possibility of similar occurrences.

CONCLUSIONS

These conclusions are directed toward the fundamental goals and purposes of the primary task. Work ancillary to those goals is described and explained in individual sections.

1. State-of-the-art methodologies are sufficiently accurate and reliable to allow easy detection of any changes in airborne bacteria that might occur as a result of changes in ventilation practice in buildings.
2. We have found no situation, as a result of the noted ventilation changes, where airborne bacteria increased above maximal levels found in other living spaces under usual (commonly accepted) ventilation rates.
3. The mean, airborne, bacteria from sequential samples of air in buildings where activities are not structured (as they are in classrooms) can be expected to have a standard deviation approximately equal to the mean value.

RECOMMENDATIONS

1. The use of diagnostic media is of little value unless a condition involving a known microorganism (e.g., accompanying an epidemiological study) is to be examined.

2. Any future study, after retrofit, should be conducted over a long time period, at least six months, to ascertain whether there is a slow, continuous increase in airborne particles to some new equilibrium level. Pre-retrofit sampling should be conducted only long enough to establish a reasonable base line (e.g. 2 weeks). Post-retrofit sampling need be done only frequently enough to detect any build-up and new equilibrium condition, if any (e.g. three sequential days, 4 samples/day, every two weeks).

3. In the final analysis, a hazardous situation can be detected only by noting an increased occurrence of human illness. That situation is best evaluated by epidemiological methods based on clinical observation.

RLD:ch
2-12-80

LITERATURE CITED

1. GOLDSTEIN, P.; WARSHAVER, P., and EAGLE, M.C. 1973. The effect of air pollutants (ozone and nitrogen dioxide) on murine resistance to pulmonary bacterial infection. In: Airborne Transmission and Airborne Infection (J.E. Ph.Hers and K.C. Winkler, eds.) Oosthoek Pub. Co., Utrecht, The Netherlands.
2. CHATIGNY, M.A.; WOLOCHOW, H.; LEIF, W.R., and HEBERT, J. 1973. The toxicity of nitrogen oxides for an airborne microbe. Ibid.