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EVALUATION OF AN AUTOMATIC AEROSOL PARTICLE COUNTER FOR MEASURING THE AIRBORNE CONTAMINATION LEVEL IN A CONTROLLED ENVIRONMENT

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ABSTRACT

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The automatic aerosol particle counter and the microscopic particle counts were in satisfactory agreement. However, the automatic counter is more efficient in counting particles at 0.6 micron or 0.75 micron as compared to the microscopist, who is restricted to counting particles 5 microns or larger.

A method of correlating the sizes and quantities of particulate contamination present at any time is submitted for consideration. By utilizing the particle size distribution curve, based on Stokes'Law, as found in Federal Standard 209 for a Class 10,000 Clean Room, the number of particles for each different size may be estimated. Acceptance of this method will make it possible to use the automatic counters in a continuous monitoring program. This will provide a prompt recording of the contamination level in the environment monitored.

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MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	1
HISTORY OF COUNTER	2
DISCUSSION OF THE INSTRUMENT OPERATION	5
VALVE CLINIC OPERATION	7
METHOD FOR USING COUNTER	11
MONITORING WITH COUNTER	15
Value Clinic Assembly Room	15
Tube Cleaning Checkout Room	23
CONCLUSIONS	23
REFERENCES	28

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Pictorial View of Original Optics	3
2.	Paths of Particles in Original Viewing Cell Chamber	4
3.	Flow Diagram of Modified Aerosol System	6
4.	Royco Count versus Millipore Count - Disassembly Room	10
5.	Royco Count versus Millipore Count - Assembly Room	13
6.	Particle Size Distribution Curve	14
7.	Royco Count versus Time, Valve Clinic, August 26, 1965	17
8.	Royco Count versus Time, Valve Clinic, August 30, 1965	18
9.	Royco Count versus Time, Valve Clinic, September 1, 1965	19
10.	Royco Count versus Time, Valve Clinic, September 2, 1965	20
11.	Royco Count versus Time, Valve Clinic, September 9, 1965	21
12.	Royco Count versus Time, Valve Clinic, September 10, 1965	22
13.	Royco Count versus Time, Tube Cleaning Area, September 16, 1965	24
14.	Royco Count versus Time, Tube Cleaning Area, September 17, 1965	25
15.	Royco Count versus Time, Tube Cleaning Area, September 20, 1965	26
16.	Royco Count versus Time, Tube Cleaning Area, September 21, 1965	27

LIST OF TABLES

Table		Page
I.	Comparison of Particle Counts in Disassembly Room	9
II.	Comparison of Particle Counts in Assembly Room	12
III.	Particle Sizes and Quantities Allowable in a Class 10,000 Clean Room	16

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SUMMARY

The Royco Aerosol Particle Counter, as modified by the IIT Research Institute, is the best instrument available for the continuous monitoring of the airborne particulate contamination in the controlled environment of a clean room because of the short time required to obtain results. In addition, it prints out the contamination level of the atmosphere being monitored, showing the contamination level during a specific period. These continuously recorded readings may be compared with each other, thus disclosing trends. The data may be plotted on a graph for convenient study; unusually high counts may thus be associated with specific events in the room being monitored. The instrument is equipped with an alarm system which may be used to alert personnel to the fact that the contamination level has exceeded predetermined limits.

The correlation between the microscopic sizing and counting of the airborne particulate contamination that has been collected on a membrane filter, and that performed by the automatic particle counter has been satisfactory and has shown that the two methods vary in direct proportion. The instrument shows variations in the contamination in the environmental air within minutes; however, it takes longer than an hour to complete and verify the microscopic examination of a filter.

The use of the Particle Size Distribution Curve for a Class 10,000 Clean Room, as found in Federal Standard 209, which is based on Stokes' Law and referenced in this note, is an aid in interpreting and correlating the data obtained by this counter.

INTRODUCTION

These tests were conducted to determine the feasibility of using the Royco Aerosol Particle Counter (Royco), as modified by the IIT Research

Institute, in monitoring the airborne particulate contamination in the controlled environments in the Valve Clinic of the Manufacturing Engineering Laboratory. This report is based on tests conducted within the Valve Clinic and the tube cleaning area during the last several months with the assistance of personnel of the Valve Clinic and the Engineering Section who have been responsible for the routine monitoring.

HISTORY OF COUNTER

There was unsatisfactory agreement between the counts obtained by the Royco Automatic Aerosol Particle Counter and the counts obtained by the microscopic examination of the contamination collected on a Millipore filter at the same time and place. In an effort to obtain a more representative sample, the size of the sample was increased. For discussion, assume the following:

$$\frac{\text{Particles in Sample}}{\text{Particles in Room}}$$

$$= \frac{\text{Cross Section of Sampling Tube}}{\text{Cross Section of Room}} \cdot \frac{\text{Volume of Sample}}{\text{Volume of Room}} \cdot \frac{\text{Volume of Sample Scanned}}{\text{Volume of Sample}} .$$

Contract NAS8-11115 was awarded to the IIT Research Institute (IITRI) to develop and improve the Royco air analyzer to upgrade this instrument. The following improvements were made:

1. The cross section of the sampling tube was increased one-hundred fold. The diameter was increased from 1.6 mm to 16.0 mm.

2. The sample volume was increased about 140 times by increasing the rate of sampling flow from 200 milliliters (ml) per minute to approximately 1 cubic foot or 28.3 liters per minute.

3. A larger volume of the collected sample was scanned by increasing the slit sizes and increasing the volume of the zone scanned at any one time.

4. Referring to the circular blow-up on Figure 1, it will be noted that the viewing zone is larger than the sample volume. This permits the scanning of particles in the turbulent zones at the edge of the flow of air. Referring to Figure 2, it will be noted that there is a strong possibility of a particle being counted more than once because of the existence of the surrounding turbulent air zone.

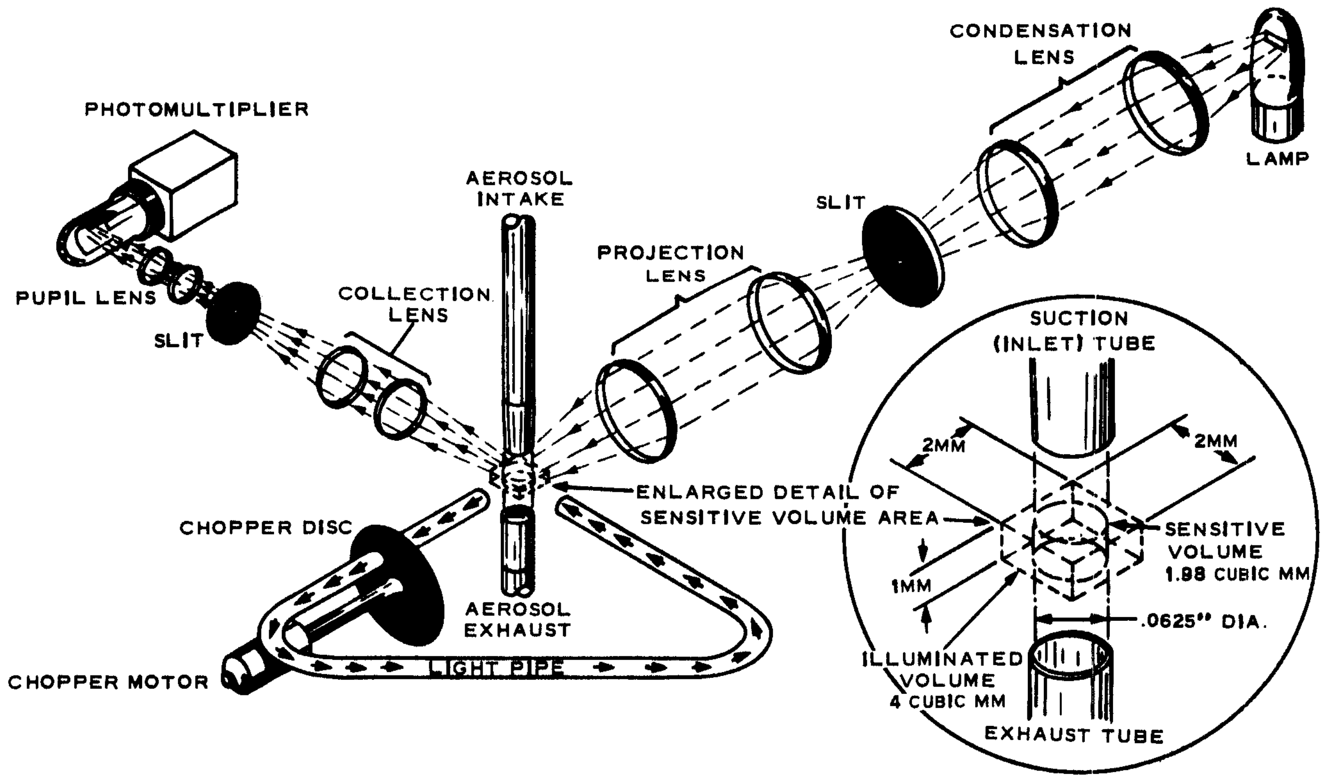


FIGURE 1. PICTORIAL VIEW OF ORIGINAL OPTICS

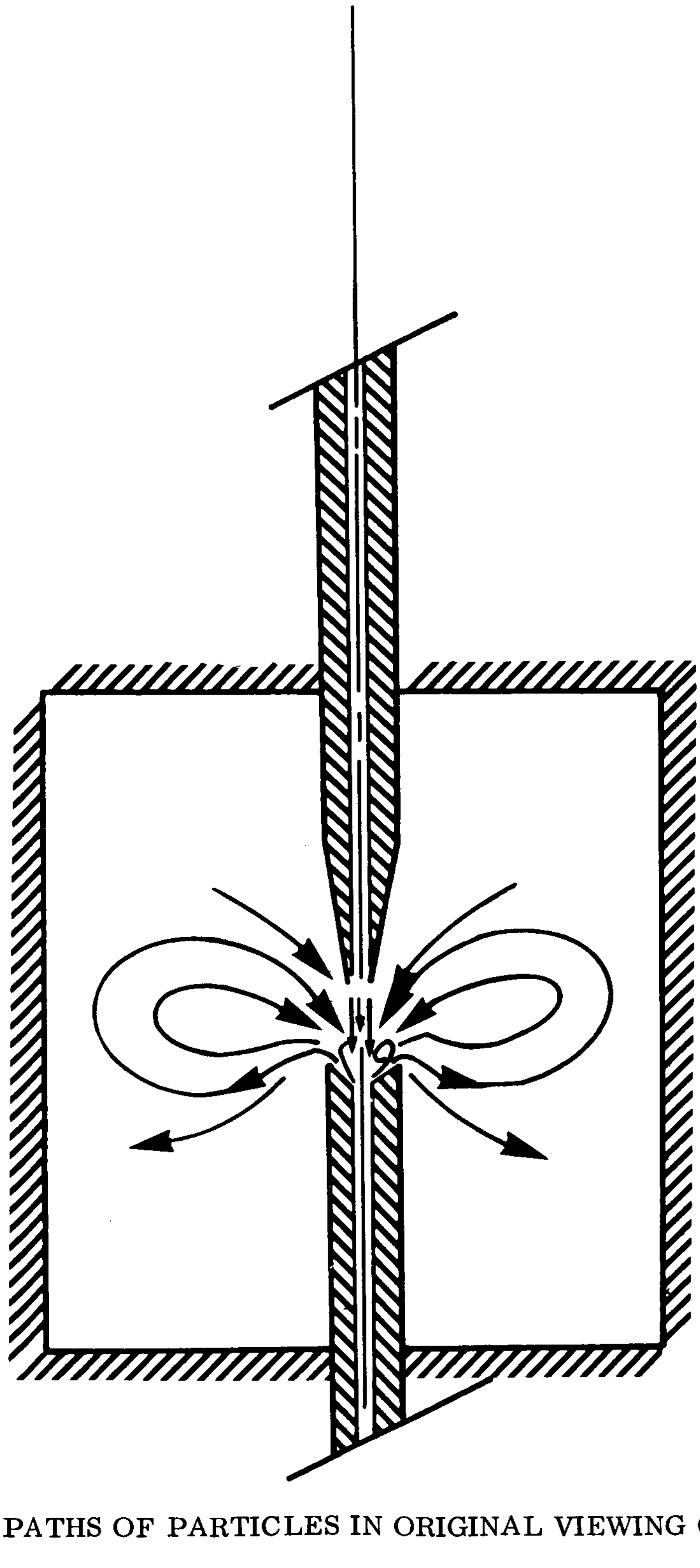


FIGURE 2. PATHS OF PARTICLES IN ORIGINAL VIEWING CELL CHAMBER

The existence of the turbulent zones has been greatly reduced in the modified instrument by providing an air sheath (Fig. 3). The flow of air through the viewing zone is controlled by adjusting the calibrated flowmeters. The scanning zone is well inside the areas that might be effected by the air turbulence. These changes practically eliminate the possibility of counting a particle more than once. It should be noted that the volume of the scanning zone is two percent of an equivalent volume of the sampling zone. Therefore, the count observed in the scanning zone must be multiplied by 50 to get the total number of particles in the equivalent volume in the sampling zone.

5. The light source was improved by substituting a ribbon filament steady high intensity lamp for a coiled filament tube. A fuse and a switch were also installed to protect and control the lamp.

6. An improved type of photomultiplier tube was installed.

7. The above changes necessitated electronic adjustments which resulted in improving the sensitivity and discrimination of signal variations in the instrument.

8. The method of internal calibration within the unit was improved so that more and finer adjustments could be made, thus allowing for corrections that would compensate for lamp filament deterioration. A calibrated voltmeter was substituted for the existing calibration meter. When the photomultiplier voltage becomes excessive, the lamp source can be changed or replaced. Also, the photomultiplier voltage and the sensitivity of the instrument can be adjusted to the particle sizes monitored.

DISCUSSION OF THE INSTRUMENT OPERATION

The Royco operates on the light scattering principle. An intense beam of light is directed into a chamber, through which the sample air is drawn. The light from the beam, which is scattered at right angles by the passing particles, is reflected into a photomultiplier tube from which the impulses are amplified, sorted, and recorded.

This information is transmitted to a decade counter and printed on a tape. The information on the tape shows the time of the sample period, the channel (which designates the size of the particles), and the total number of particles that size or larger. The time that a count is completed is printed on the left

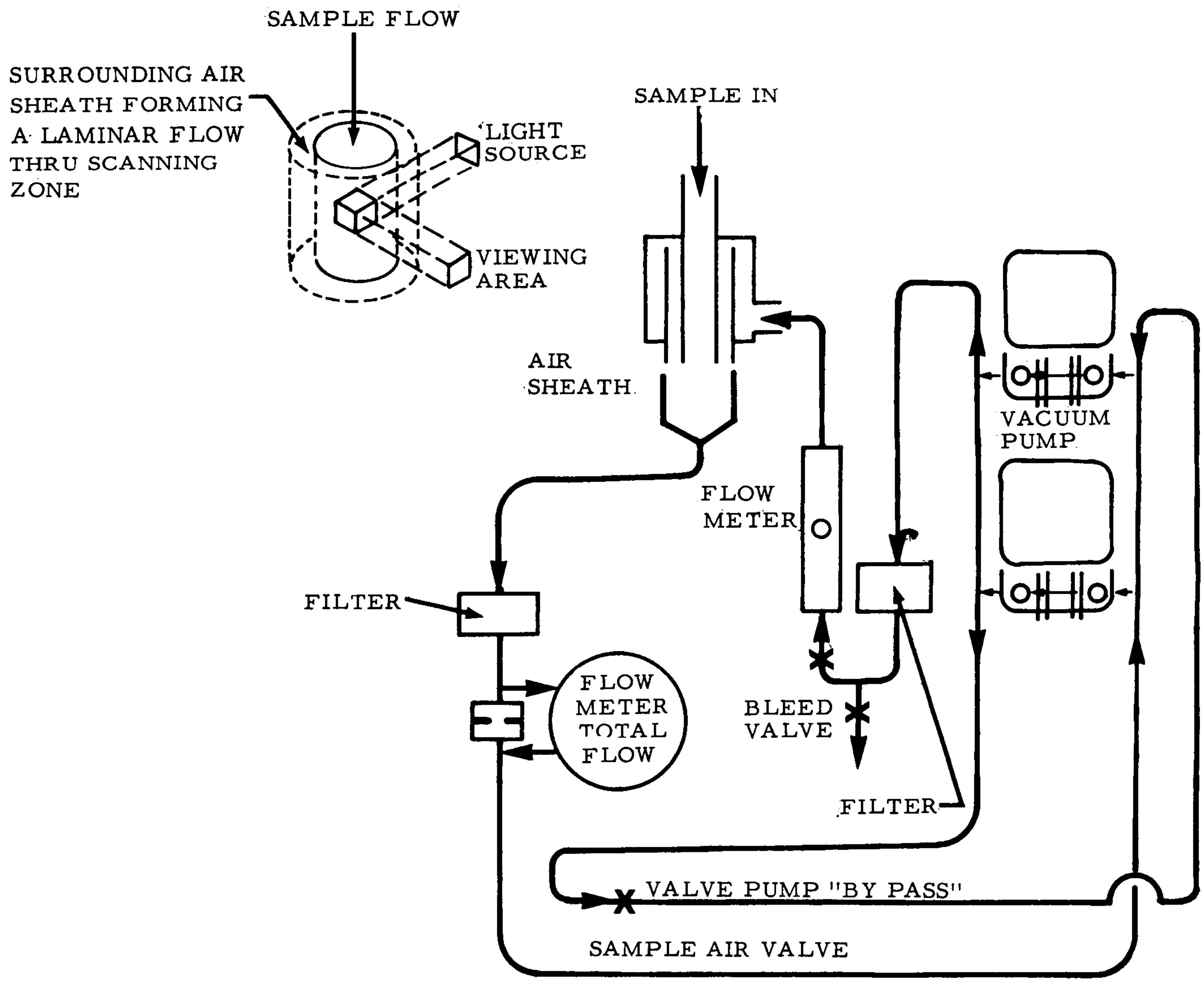


FIGURE 3. FLOW DIAGRAM OF MODIFIED AEROSOL SYSTEM

side of the tape in four digits. The next one or two digits indicate the channel counted, and the five right-hand digits indicate the total number of counted particles greater than the size shown by the channel [1].

It was found to be easier and more accurate to count all particles greater than a single size instead of taking the count for several intermediate particle sizes.

For these reasons, the ten minute interval for one channel was chosen. The channel selected was the one equivalent to 4.6 microns, which was the one nearest to 5 microns, the smallest size that can be counted satisfactorily with the available microscopic equipment.

Since an operating manual is available for the modified Royco instrument, detailed instructions for calibration and operation of the instrument will not be discussed in this report.

This is the type instrument mentioned in Federal Standard 209, paragraph 5.5.1(a):

> "For particle sizes 0.5 microns and larger, automatic equipment employing light scattering principles shall be used. This applies to particle counting and particle concentration indicating devices which have been calibrated to give particle number information." [2]

The instrument used in these tests is identified by the Marshall Space Flight Center property tag MSFC 7327.

VALVE CLINIC OPERATION

Because of the possibility of getting larger particles in the Disassembly Room of the Valve Clinic, the initial samples were taken there. Since particle sizes smaller than 5 microns could not be counted by the microscopic examination of the contamination on a membrane filter, it was desirable to get a larger proportion of large particles.

As in any tests of this sort, the results would be only as good as the samples. Consideration of collecting the filter sample from under the Royco viewing zone was abandoned because it would be necessary to dismantle the instrument extensively. The filter sample was collected by placing the Millipore sampling device, designed for sampling the particulate contamination in clean room garments, within an area 4 to 6 inches from the open mouth of the Royco sampling tube. The air was drawn through the Millipore filter by a Cleanline Air Sampler, a device made by the Controlled Environment Equipment Corporation. This is commonly known as a "sniffer" which consists of a white box enclosing a vacuum pump, a time switch, and a flowmeter. By means of the flowmeter, a maximum flow of between 56 and 58 standard cubic feet of air per hour (1562 to 1650 liters/hr) were drawn through a black gridded, 0. 8 micron pore size Milipore filter. This flow was equivalent to about 0. 95 cubic feet of air per minute. This was practically the same flow that was drawn through the sampling tube of the Royco. The flowmeters of the Royco showed a lineal flow of 2. 3 meters per second which was comparable to 0. 97 cubic feet of air per minute.

Several improvements in sampling techniques were made while taking these initial samples. The use of aluminum foil as a protective cover was discontinued because of the possibility of introducing too many extraneous particles into the sample. A Millipore garment sampler was used on all subsequent samples because the pre-filter device could be used as a protective cover.

Samples were taken by starting the Millipore filter sample just as the counter started one of its cycles. Previous samples which had been taken by the Royco for short periods showed very high peaks. It is believed that the airborne particles float in clouds. This is the only reasonable way to account for these sharp peaks and abnormally high readings that we find in the graphs. To assure a more uniform pattern, the samples were taken over half-hour periods, or during three ten-minute intervals, as timed by the instrument.

The number of particles larger than 5 microns in a cubic foot of sampled air was calculated from these data (Table I, and Figure 4). The findings at any specific time were plotted on equal vertical and horizontal scales. If the coordinates had been equal, all the points would have been on a line at a 45 degree angle. This was not the case, for a line through the average was about 65 degrees from the horizontal. This indicates that the instrument reading is approximately twice that of the Millipore filter reading. Had the reverse been true, it might have been expected that extraneous contamination had been introduced into the filter. An occasional background count on the Royco may have caused the instrument to record a little higher count, but it would not account for such wide differences in counts.

The instrument was cleaned and moved into the Valve Clinic Assembly Room in Building 4705. To be out of the way and near a convenient electric outlet,

TABLE I. COMPARISON OF PARTICLE COUNTS IN DISASSEMBLY ROOM

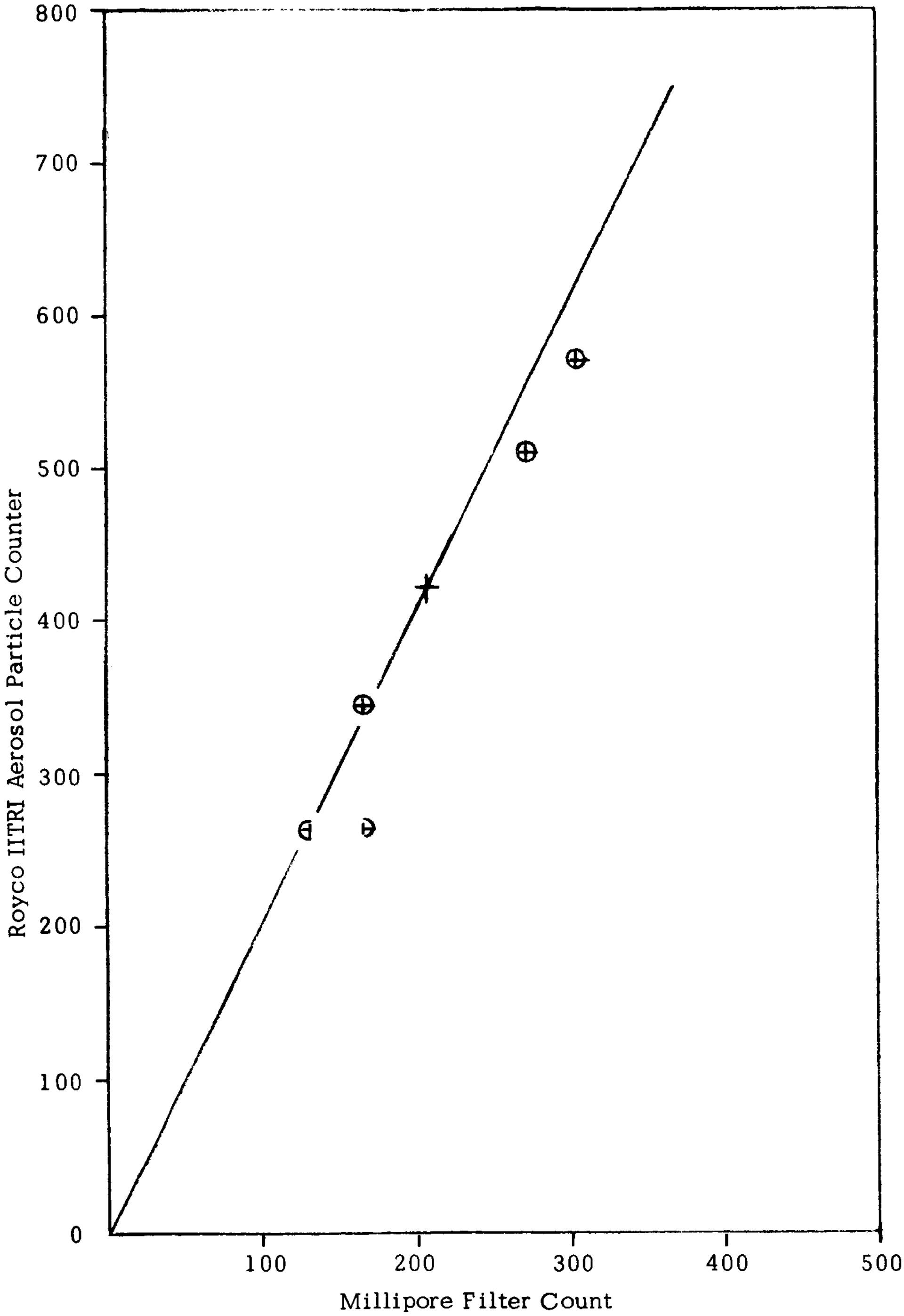
Sample	Minutes Sampled	Royco Count[a]	Number of Particles[b]	Number of Particles[c] / ft³ (Royco IITRI Count)	Number of Particles / ft³ (Millipore Sample)	Number of Particles (Millipore Sample)
1	30	327	16350	570	306	8434
2	30	150	7500	263	134	3687
2(a)*					166	4553
3	30	292	14600	519	272	7500
4	30	197	9850	345	167	4594
Average Counts				422	209	

a. All particle counts are the total number of particles greater than five microns.

b. Royco Count X 50 = Number of Particles

c. $\frac{\text{Number of Particles}}{\text{Sample Size } (ft^3)} = \frac{\text{Number of Particles}}{ft^3}$

* Millipore filter counted by a second microscopist.



NOTE: Graph 1 based on Table 1 MD-7-65.

FIGURE 4. ROYCO COUNT VERSUS MILLIPORE COUNT - DISASSEMBLY ROOM

the instrument was placed along the south wall of the room--just east of the double access doors from the equipment airlock. A return air duct located in the wall nearby contributed to obtaining a good representative sample of the air.

The Millipore filter sample was taken in a fashion similar to that described previously. When the Royco started a new counting period, the pump in the sampler was started and the flow rate was adjusted to the same rate that the Royco sampled the air. When the Royco printed the results, the Millipore sampling was stopped.

The total sampling times were varied during these tests in an effort to see if there would be an optimum sampling time. The length of the sampling period made little difference as long as there were sufficient particles to be counted. It should be noted here that there should be at least five hundred particles fairly evenly distributed on a filter in order to obtain a good statistical count [3].

The results of these tests are tabulated in Table II and are shown graphically in Figure 5. Here the total number of particles greater than five microns in 28.3 liters or 1 cubic foot has been plotted on equal scales for both the Royco and the Millipore counts. Had these been equal, they would have generated a line at 45 degrees from the horizontal. This is closer to the ideal than the results in the disassembly room. In this location many more samples were taken. The Royco read about 30 percent higher than the filter count. This is within the limits allowed between technicians reading a filter.

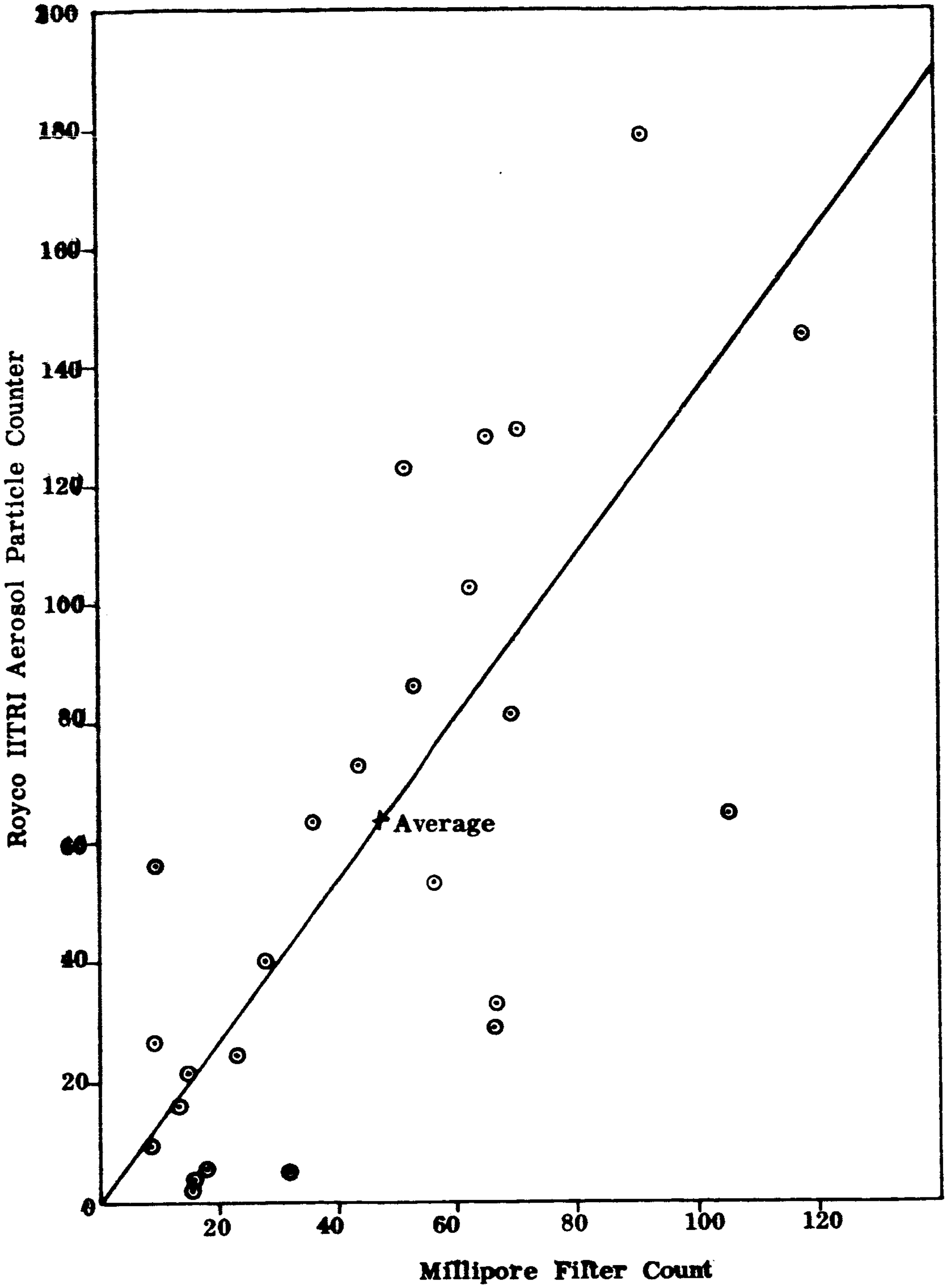
Most of these counts were taken with the Royco set to count all particles greater than 4.62 microns, because this was the nearest obtainable setting to five microns. A comparison with the Particle Size Distribution curve on Figure 6, shows that for 65 particles at five microns, there will be approximately 78 particles at 4.6 microns. This shows an increase in count of about 20 percent. It is doubtful that a microscopist could measure that closely; this may have had some effect on the results, causing the Royco count to be proportionally higher.

METHOD FOR USING COUNTER

By means of the microscopic examination of contamination collected on a membrane filter, the microscopist can visually size and count particles down to five microns in size.

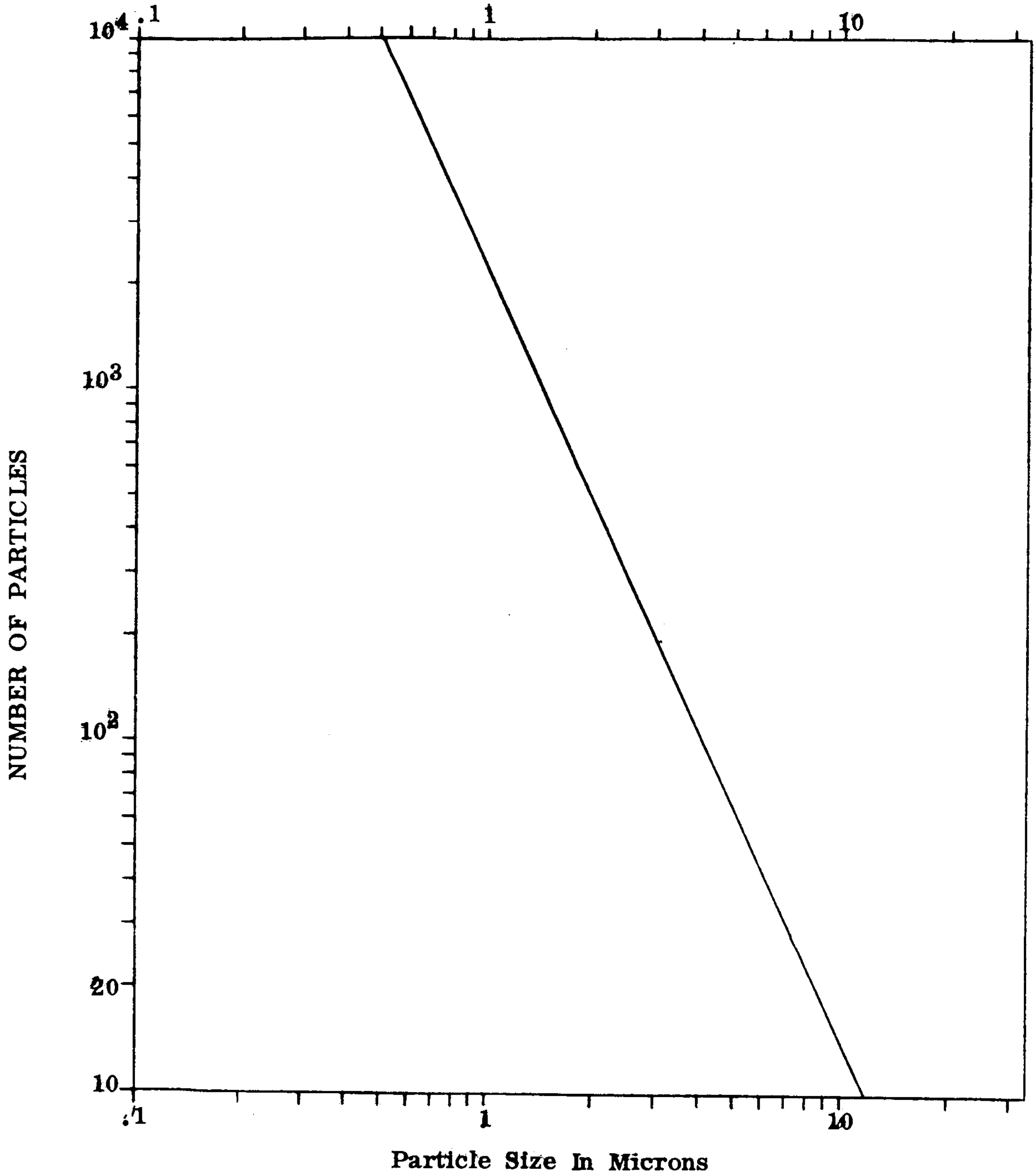
TABLE II. COMPARISON OF PARTICLE COUNTS IN ASSEMBLY ROOM

Sample	Minutes Sampled	Sample Size (ft^5)	Royco Count	Number of Particles	Number of Particles per ft^3	Number of Particles per ft^3	Number of Particles	Sample Size (ft^3)
1	48	46.6	31	1550	33	67	3000	44
2	36	35	20	1000	28.5	67.5	2226	33
3	21	20.4	11	550	27	9.6	185	19.3
4	18	17.5	30	2250	129	71	1165	16.5
5	60	58.2	1	50	1	15.5	855	55
6	24	23.2	1	50	2.2	15.2	340	22
7	24	23.3	48	2400	103	63	1384	22
8	18	17.5	51	2550	145	119	1955	16.5
9	36	34.9	124	6200	178	92	2925	31.9
10	18	17.5	5	250	14.4	13.3	220	16.5
11	96	93	74	3700	40	28.5	2520	88
12	30	29	15	750	25.8	22.6	621	27.5
13	60	58.2	143	7150	123	52	2593	55
14	60	58.2	19	950	16.4	19.5	1075	55
15	60	58.2	61	3050	52.5	56.3	3116	55
16	66	64	92	4600	72	44	2772	58.5
17	63	61	156	7800	128	66	3825	57.8
18	93	90.5	114	5700	63	36.4	3100	85
19	12	11.62	13	650	56	9.7	97	10
20	12	11.6	15	750	64.6	105.5	1055	10
21	12	11.6	5	250	21.6	14.2	142	10
22	12	11.6	20	1000	86.2	52.9	529	10
23	12	11.6	2	100	8.6	7.2	72	10
24	12	11.6	1	50	4.3	31.8	318	10
25	12	11.6	19	950	81.8	69.6	696	10
26	12	11.6	48	2400	207	132.4	1324	10
27	12	11.6	1	50	4.3	17.7	177	10



NOTE: **Graph 2 based on Table 2 MD-7-65.**

FIGURE 5. ROYCO COUNT VERSUS MILLIPORE COUNT - ASSEMBLY ROOM



NOTE: Based on FED. STD. 209

FIGURE 6. PARTICLE SIZE DISTRIBUTION CURVE

By means of the Royco Counter, it was found that the best counts were obtained in the range of 0.6 to 0.7 micron. Instrument MSFC 7327 has been calibrated at 0.528 micron, 0.624 micron, and 0.738 micron in the lowest channels. Background counts often interfere with the lowest size range and may interfere excessively with the next size range, but seldom interfere at the third range.

Thus, there is a rather large gap in the counting capabilities of the two methods, with the instrument counting in the range of 0.7 micron and the microscopist counting down only to five microns. Figure 6, however, provides a means of bridging this gap. This curve was reproduced from Federal Standard 209, paragraph 5, Table 1, and shows the maximum number of particles allowed per cubic foot in a Class 10,000 clean room. Figure 6 is based on Stokes' Law.*

Table III is based on Figure 6. The particle sizes shown on this chart correspond to those sizes which the Royco Counter (MSFC 7327) is capable of counting. Based on the characteristics of the instrument, column three shows the readings corresponding to the maximum allowable limits of the number of particles of a particular size.

This chart is especially useful in setting the alarm on the Royco Counter (MSFC 7327). By setting the count in the third column, corresponding with the particle size being monitored, on the alarm in the instrument, the alarm will alert the personnel in the clean room to the fact that the airborne particulate contamination is approaching the maximum allowable limit.

MONITORING WITH COUNTER

Valve Clinic Assembly Room

A series of graphs (Figs. 7 to 12) has been prepared showing the contamination level at ten minute intervals over a period of days. These graphs show how the airborne contamination varies directly with the number of people in the room and their activity. They also demonstrate the remarkable recovery characteristics of the valve clinic assembly room

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* For a comprehensive study on the derivation of this curve and the verification of its validity, refer to "Design and Operation of Clean Rooms" by Phillip R. Austin and Stewart W. Timmerman [4].

TABLE III. PARTICLE SIZES AND QUANTITIES ALLOWABLE IN A CLASS 10,000 CLEAN ROOM

Particle Size in Microns	Max. Number Per Cu. Ft. Allowed in a 10,000 Clean Rm.	Royco IIRTI Counter (MSFC 7327) Reading Corresponding to Maximum Allowable Limits
0.500	10,000	1880
0.528	8,900	1675
0.624	6,200	1170
0.738	4,300	810
0.872	3,100	564
1.000	2,200	413
1.028	2,050	385
1.215	1,430	269
1.43	1,020	192
1.70	700	132
2.00	500	94
2.37	350	66
2.80	240	45
3.31	165	31
3.91	102	19
4.62	77	15
5.00	65	12
5.47	54	10
6.45	38	7

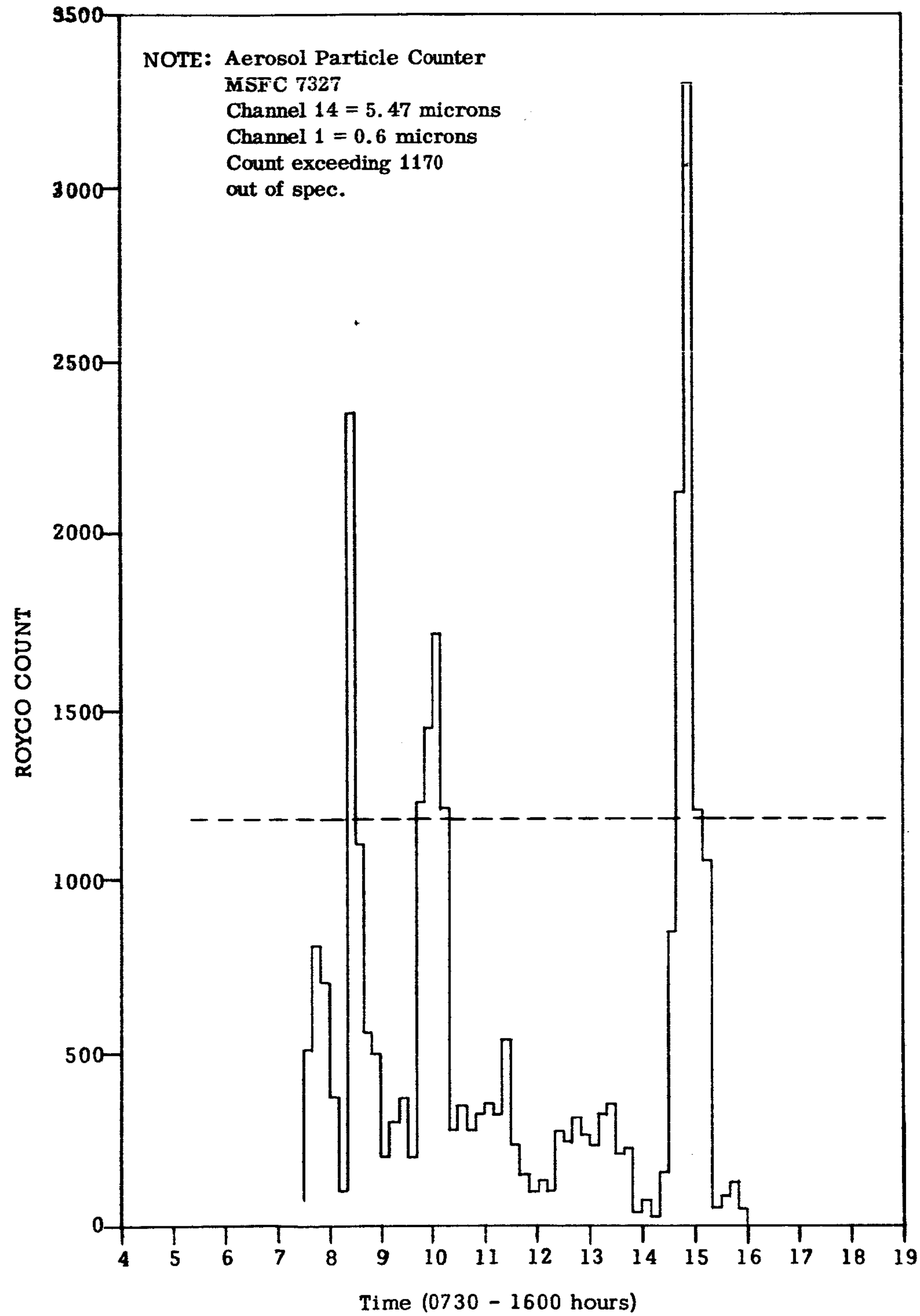

FIGURE 7. ROYCO COUNT VERSUS TIME, VALVE CLINIC, AUGUST 26, 1965

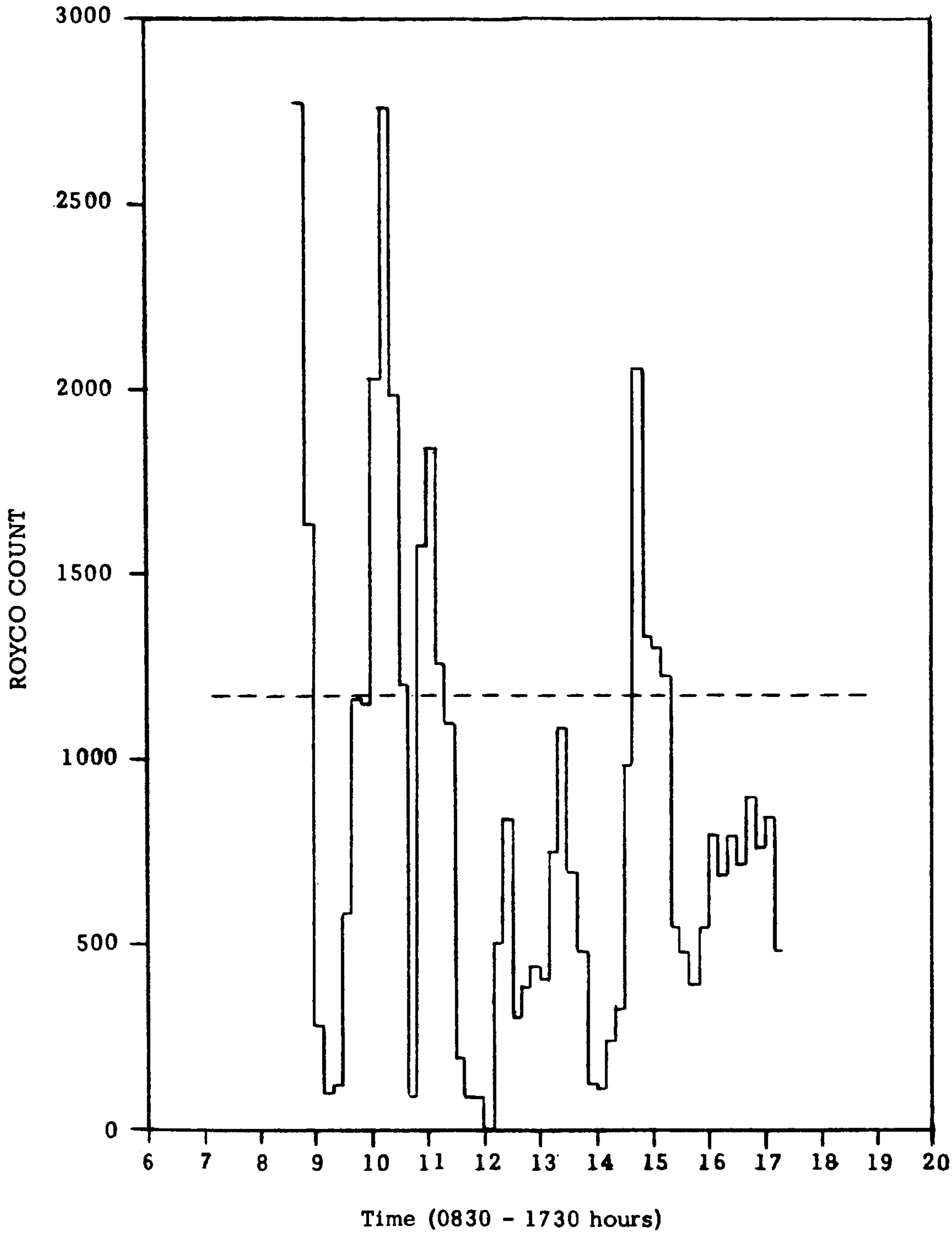

FIGURE 8. ROYCO COUNT VERSUS TIME, VALVE CLINIC, AUGUST 30, 1965

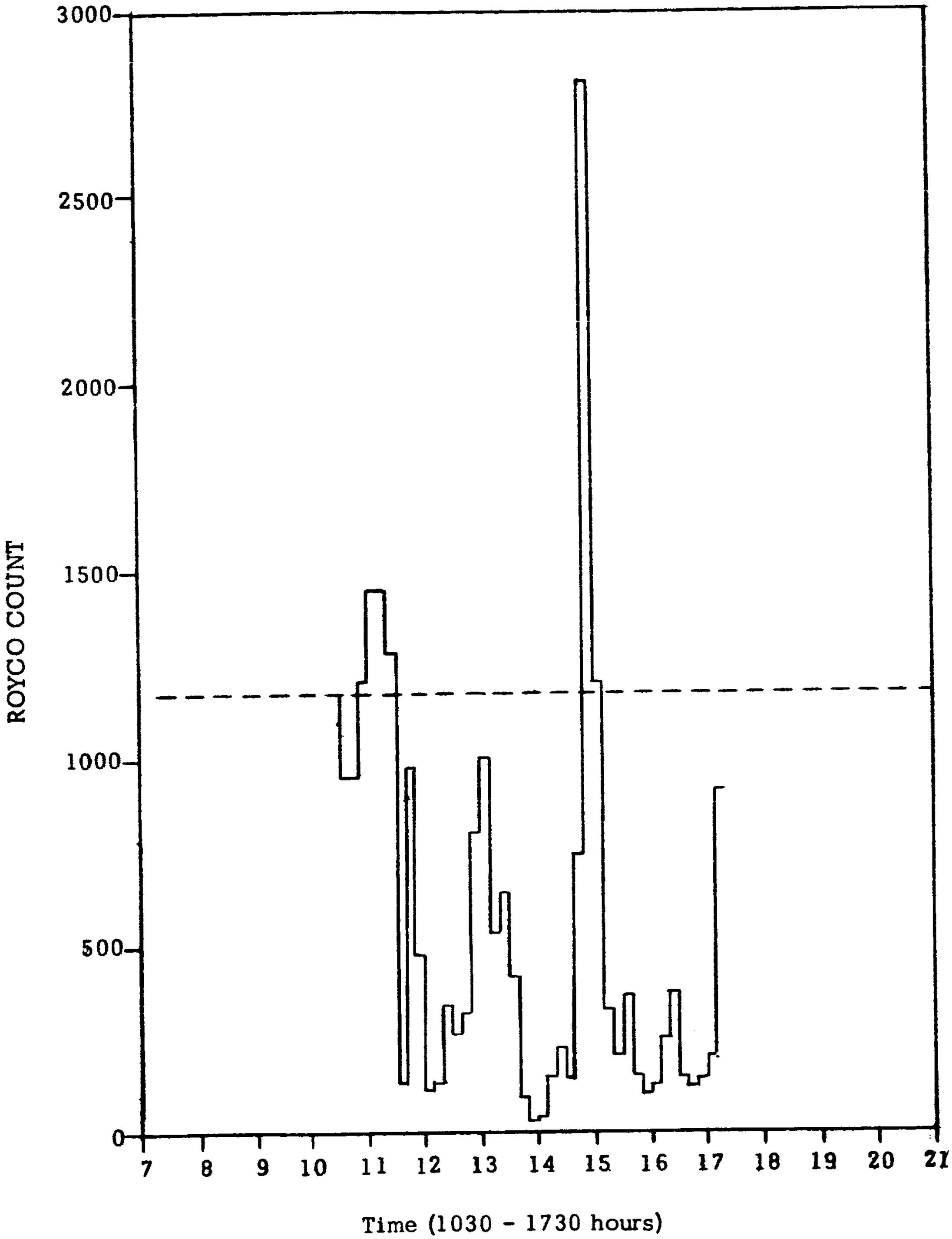

FIGURE 9. ROYCO COUNT VERSUS TIME, VALVE CLINIC, SEPTEMBER 1, 1965

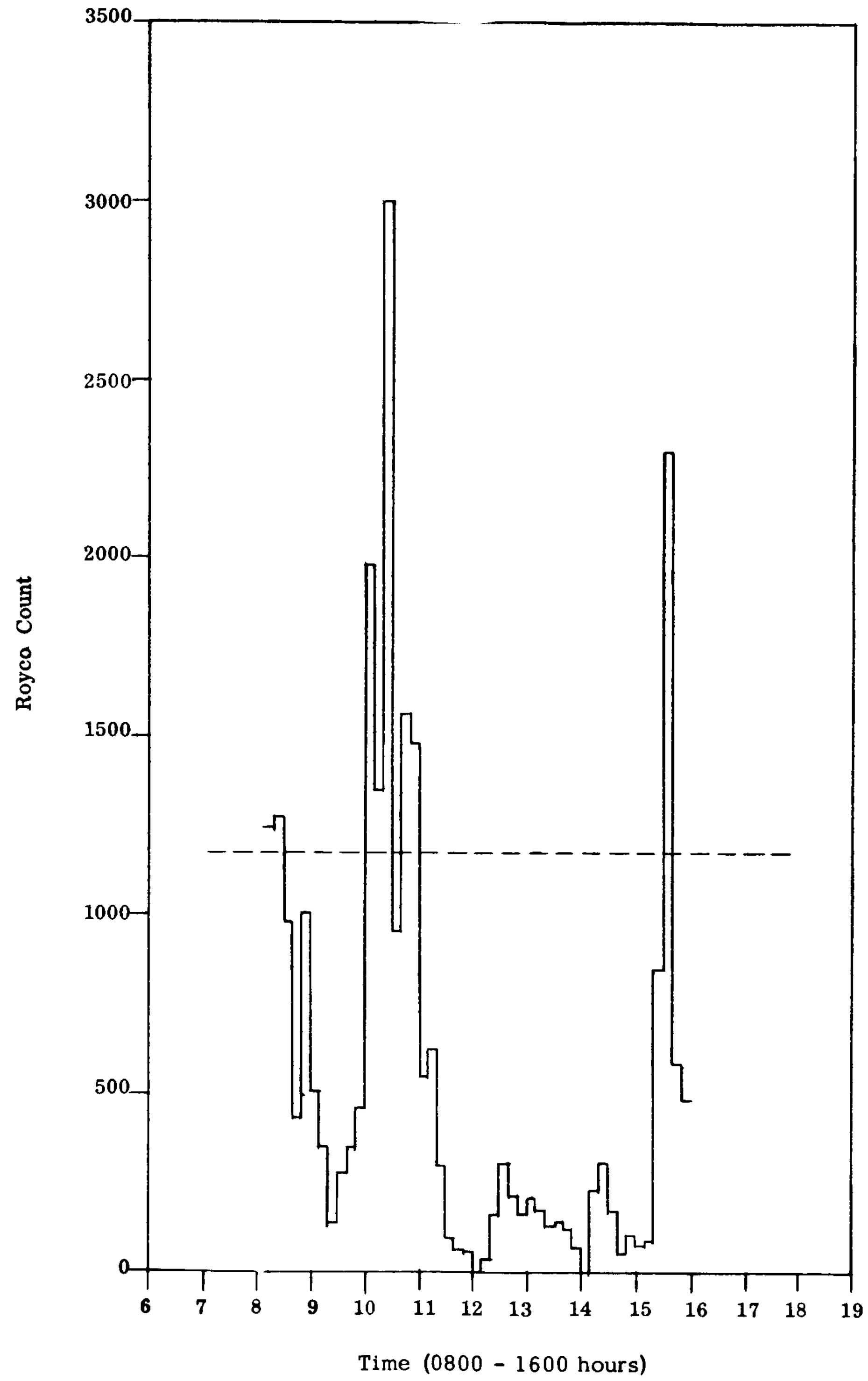

FIGURE 10. ROYCO COUNT VERSUS TIME, VALVE CLINIC, SEPTEMBER 2, 1965

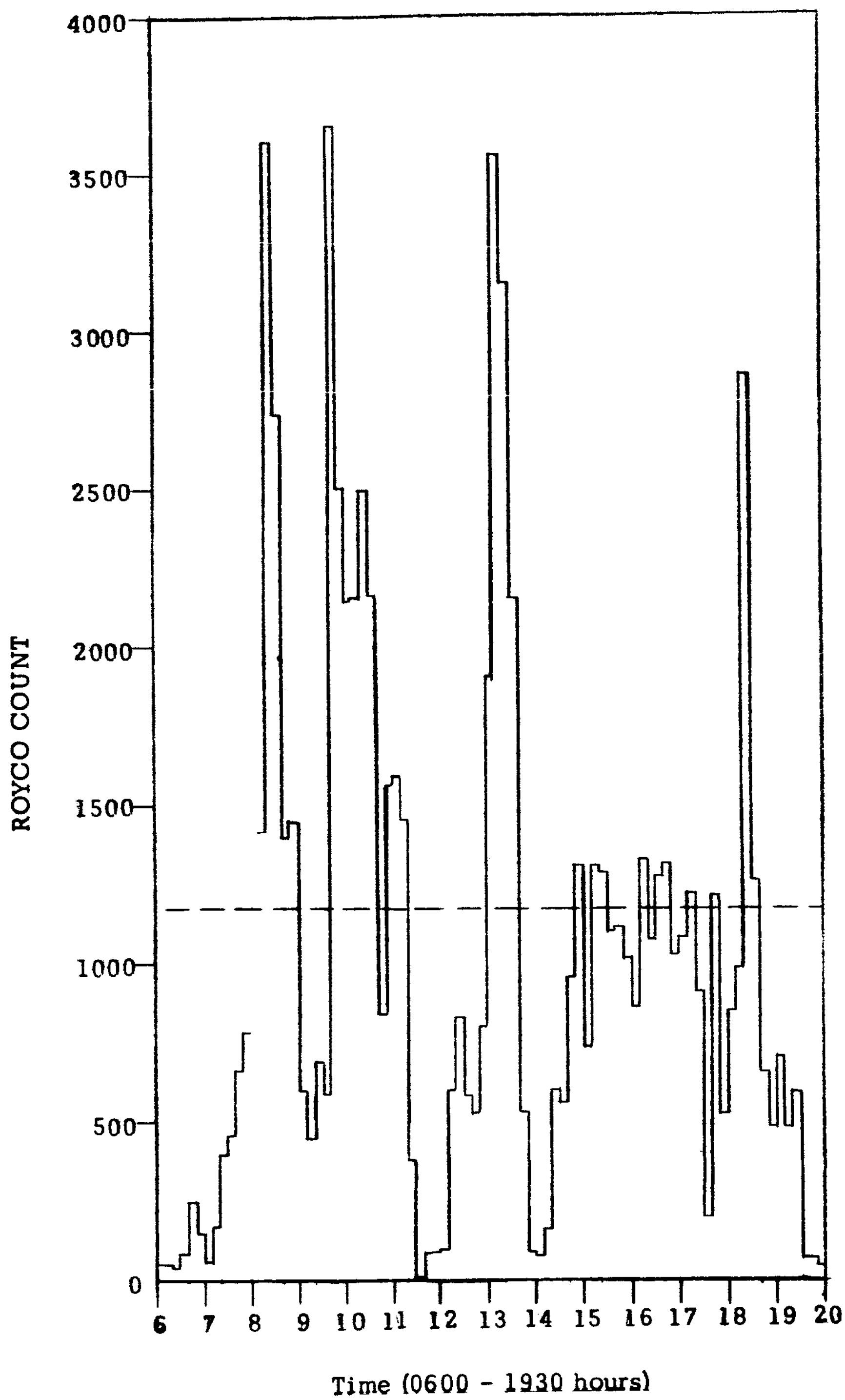

FIGURE 11. ROYCO COUNT VERSUS TIME, VALVE CLINIC, SEPTEMBER 9, 1965

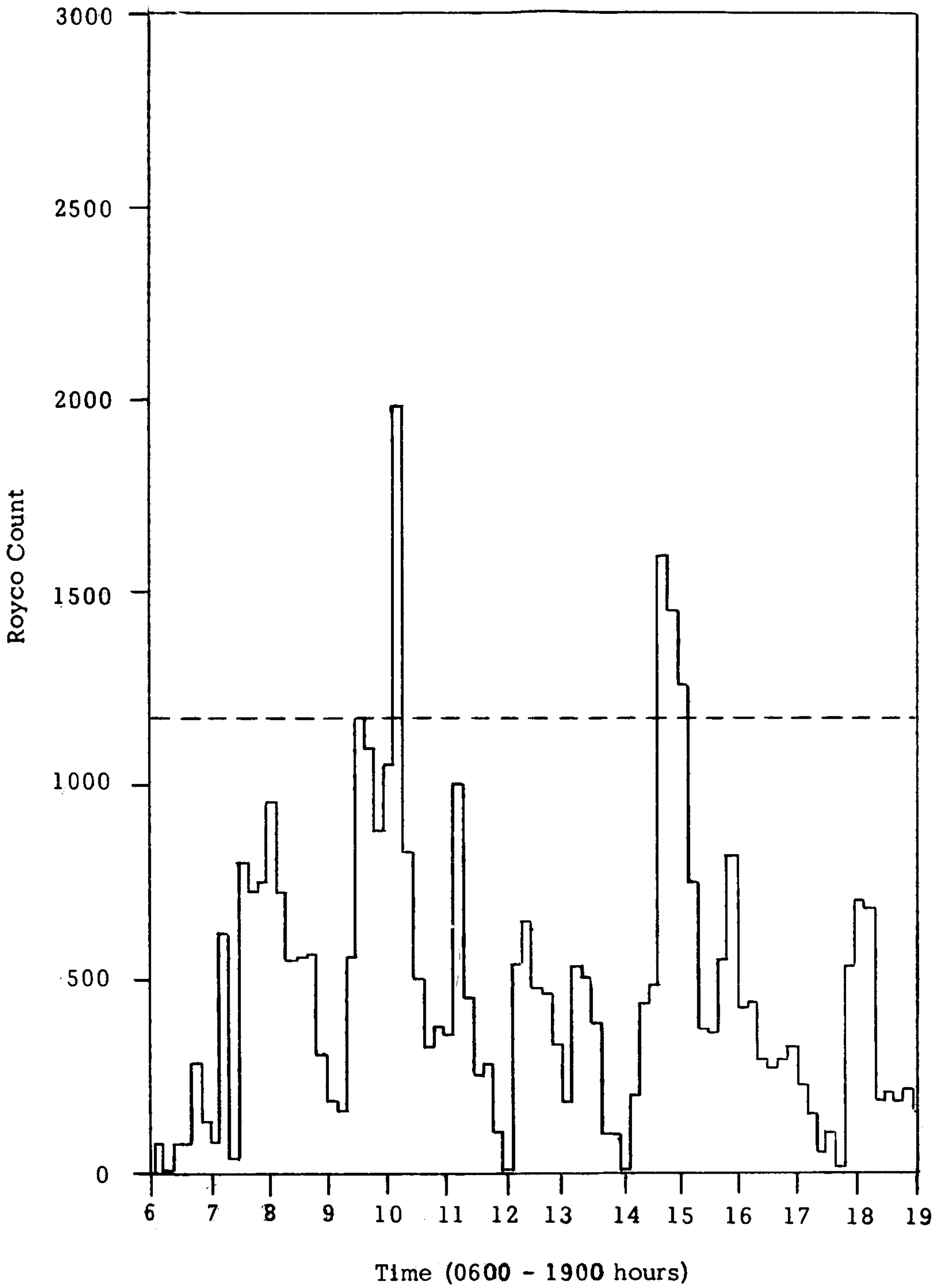

FIGURE 12. ROYCO COUNT VERSUS TIME, VALVE CLINIC, SEPTEMBER 10, 1965

Tube Cleaning Checkout Room

The graphs based on the data from the tube cleaning checkout room (Figs. 13 to 16) demonstrate the responsiveness of the counter. The instrument made it possible to compare the count when the room was unoccupied with the count when a person was in the room. The data and the graphs show that the particle count increases tremendously as soon as a person enters the room.

CONCLUSIONS

The correlation between the accepted method of testing the contamination level in a controlled atmosphere, by microscopic examination of a filter, and the use of the Royco Aerosol Particle Counter, as modified by IITRI, has been satisfactory. Some of the causes for variations in the results have been discussed and will account for some of the differences in the data obtained.

A method for using this instrument, based on the Particle Size Distribution Curve, has been devised and sufficient data has been accumulated to show that the automatic aerosol particle counter will indicate trends in the contamination level and will do this in a short enough interval to permit corrective action.

The modified Royco Aerosol Particle Counter is used to supplement the present monitoring of the controlled environments in the Manufacturing Engineering Laboratory. It provides a continuous record that will show the variations in the airborne contamination that may be related to various events occurring in the room. In addition, it signals the personnel when the airborne contamination in the room is reaching excessive levels.

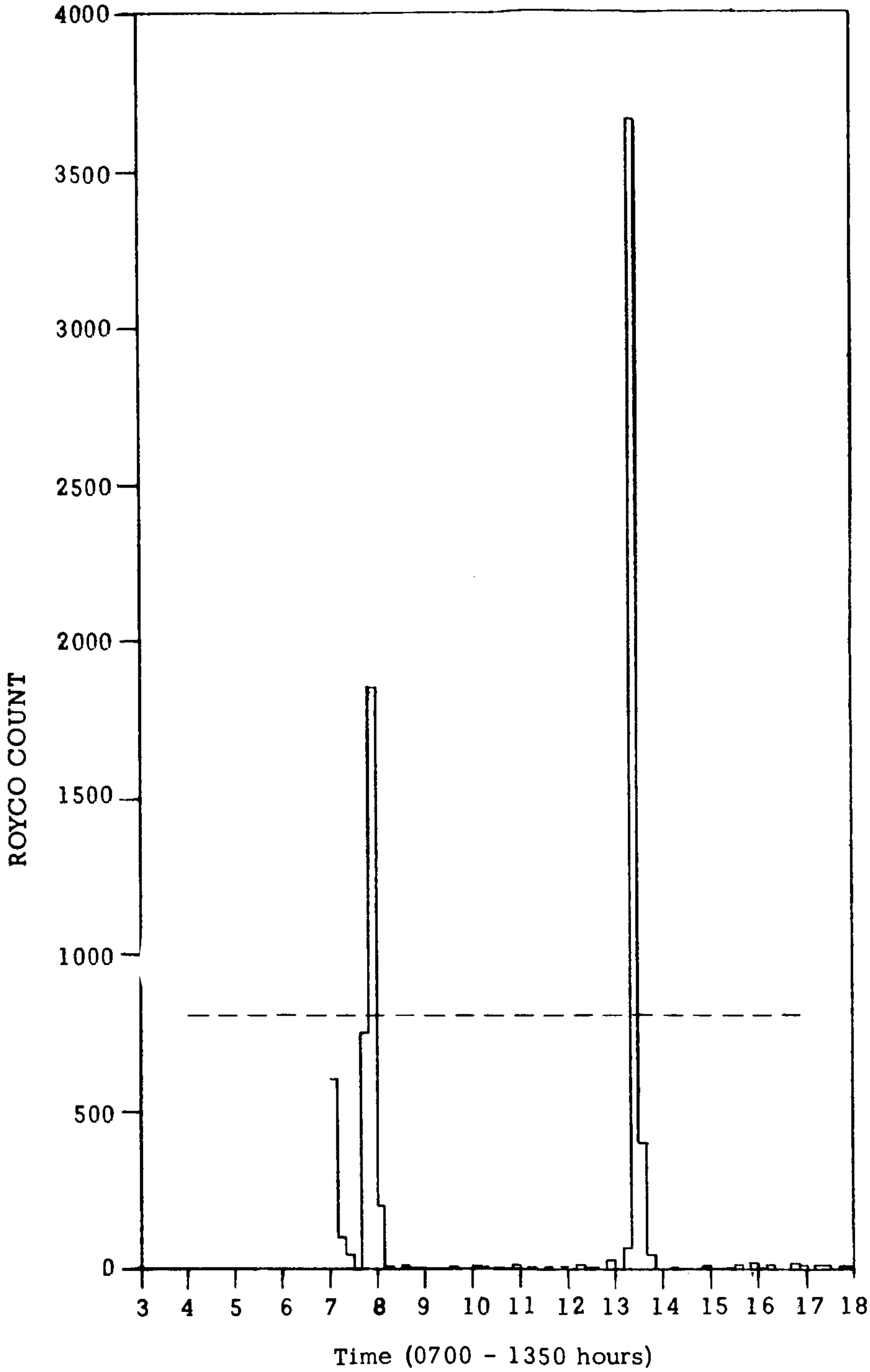

FIGURE 13. ROYCO COUNT VERSUS TIME, TUBE CLEANING AREA, SEPTEMBER 16, 1965

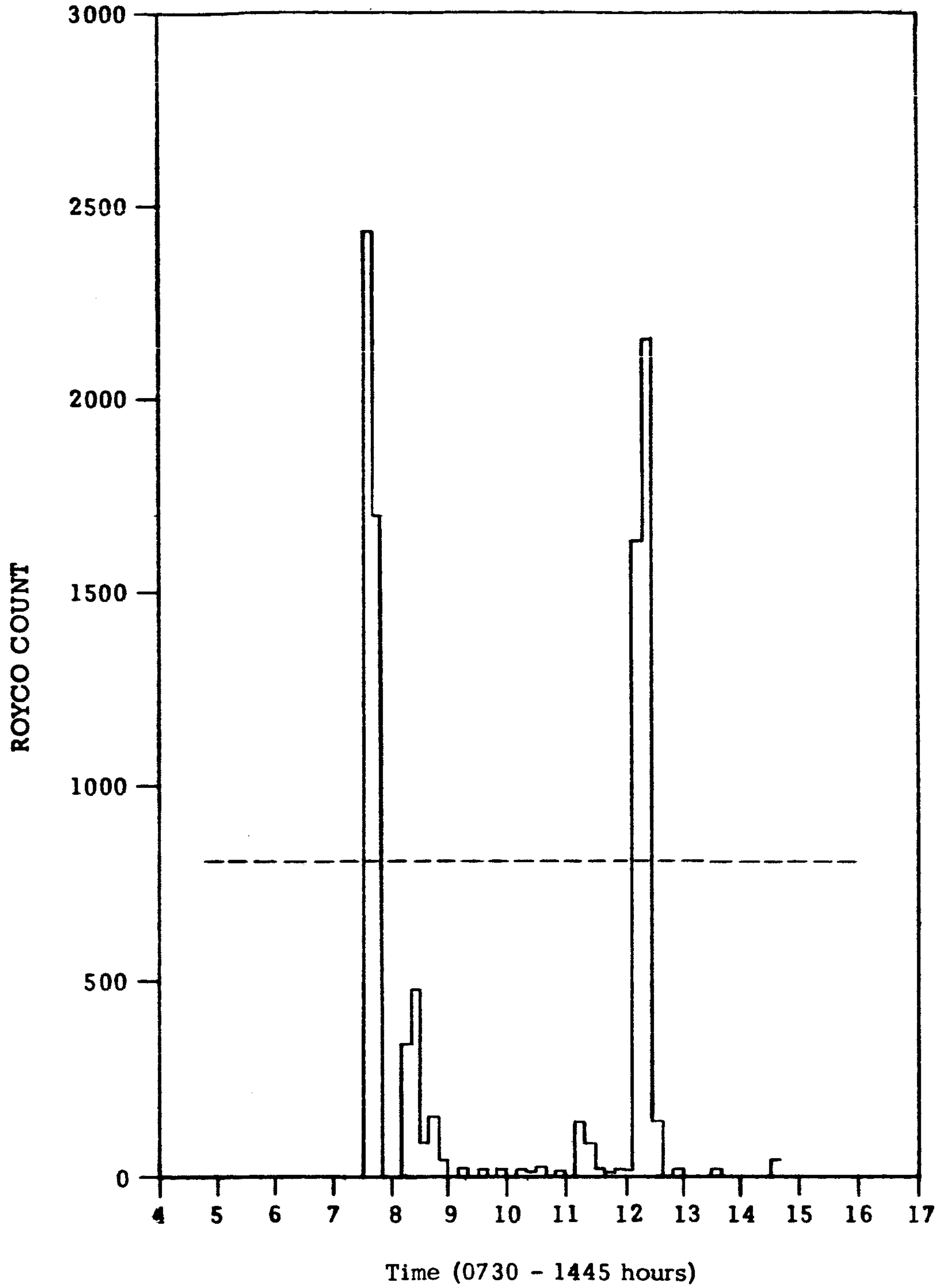

FIGURE 14. ROYCO COUNT VERSUS TIME, TUBE CLEANING AREA, SEPTEMBER 17, 1965

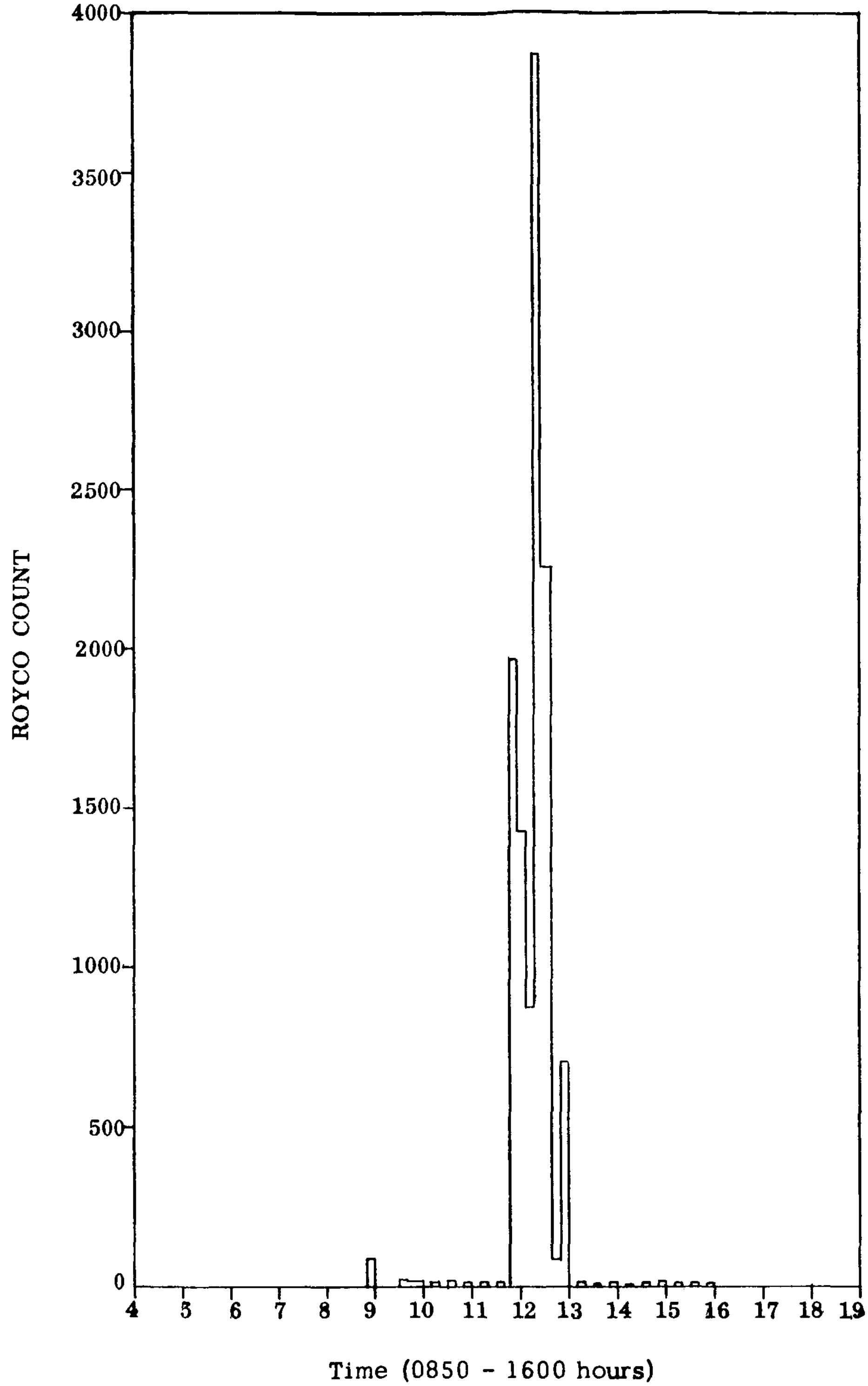

FIGURE 15. ROYCO COUNT VERSUS TIME, TUBE CLEANING AREA, SEPTEMBER 20, 1965

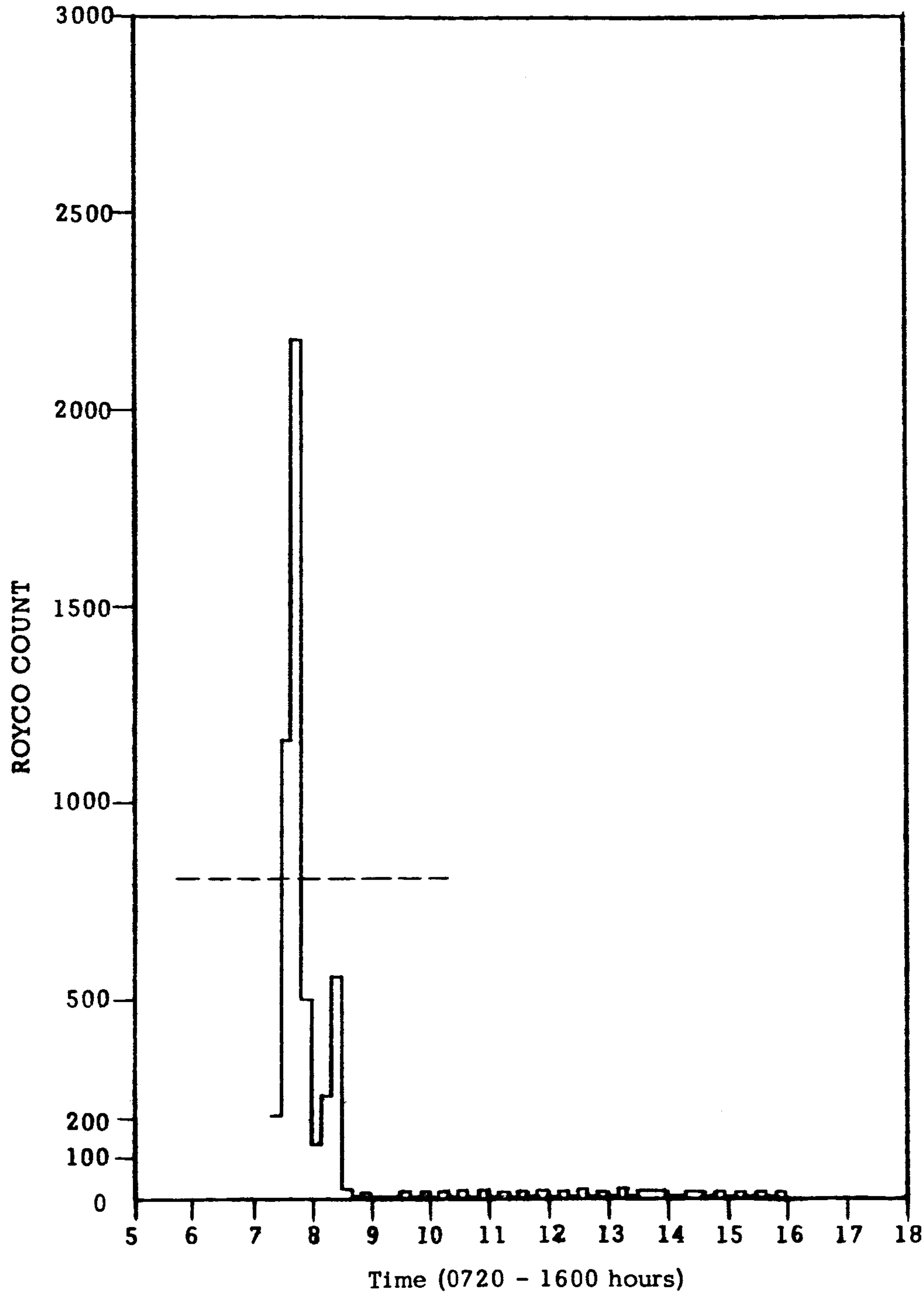

FIGURE 16. ROYCO COUNT VERSUS TIME, TUBE CLEANING AREA, SEPTEMBER 21, 1965

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4. Austin, Phillip R.; and Timmerman, Stewart W.: Design and Operation of Clean Rooms. Business News Publishing Co., 1965.

NASA TM X-53416 APPROVAL

EVALUATION OF AN AUTOMATIC AEROSOL PARTICLE COUNTER FOR MEASURING THE AIRBORNE CONTAMINATION LEVEL IN A CONTROLLED ENVIRONMENT

By Theodore W. Lewis

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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