Services Provided in Support of the Planetary Quarantine Requirements
of the
National Aeronautics and Space Administration
under Contract W-13,062

EVALUATION OF A VERTICAL LAMINAR FLOW BIOLOGICAL SAFETY CABINET

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June 1970

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Acknowledgment

The vertical laminar flow biological safety cabinet used in this evaluation was provided by BioQuest, Division of Becton, Dickinson and Company, under an agreement with the National Communicable Disease Center. The unrestricted use of this unit for experimental purposes was greatly appreciated.

Summary

A commercially available vertical laminar flow biological safety cabinet was subjected to a variety of tests to determine the degree of product and personnel protection provided under conditions of microbiological challenge. Directional and non-directional aerosols of Serratia marcescens were used to simulate sources of microbial contamination. Settling plates, Reyniers slit samplers and sieve samplers were used to detect the presence of contamination. Common laboratory practices were used to create conditions that might make the cabinet fail. Results demonstrated that failures in both product and personnel protection could be induced. However, the degree of protection provided by the cabinet was consistently high for both product and personnel. In a direct comparison of personnel protection with a conventional biological safety cabinet the laminar flow unit was consistently equal or superior.

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Part I

In accordance with the agreement between BioQuest and NCDC an evaluation of the efficiency of a vertical laminar flow biological safety cabinet in providing personnel and product protection was conducted. Because the efficacy of the laminar flow concept in controlling microbial contamination has been demonstrated in a variety of configurations this evaluation did not repeat many of the quantitative tests which would have simply corroborated existing knowledge. Instead, tests were devised to simulate certain conditions that might make the system fail.

The cabinet was assembled, filters were leak tested and airflows through the supply and exhaust fans were adjusted by a technical representative of Envirco. The cabinet was located in a laboratory as shown in Figure 1. Ventilation of the laboratory consisted of 400 cfm single pass filtered air. The laboratory was under negative pressure relative to the hallway resulting in an influx of air whenever the door to the laboratory was opened.

Microbiologic challenges of the cabinet were made with aerosols generated by either a De Vilbis 40 nebulizer when a directional aerosol was employed or a Schoeffel aerosol generator when a non-directional aerosol was used. Test suspensions were prepared by inoculating a flask containing 50 ml of Trypticase Soy Broth with a 24 hour culture of Serratia marcescens grown on a Trypticase Soy Agar (TSA) slant. The inoculated broth was incubated for 24 hours at 37 C and then refrigerated until used. The concentration of the test suspension was found to be approximately 1 x 10^9 viable cells per ml at the time of each experiment.

Test organisms were detected using TSA in Reyniers slit samplers, sieve samplers and settling plates. All plates were incubated for 24 hours at 32 C and counted. Settling plates were arranged on the work surface inside the cabinet in patterns shown in the accompanying figures. Reyniers and sieve samplers were placed at various locations inside and outside the cabinet depending on the experiment.

The first series of experiments was designed to determine whether airborne contamination outside the cabinet would penetrate into the work area.

Experiment 1:

The cabinet was turned off and a De Vilbis nebulizer was run for 5 minutes in a position 18 inches in front of the cabinet with the aerosol aimed at the opening. Eighteen settling plates arranged uniformly on the cabinet work surface as well as two Reyniers samplers outside the cabinet were all too numerous to count (TNTC).

Experiment 2:

The cabinet was turned on and an aerosol was generated as in Experiment 1. Plate counts on the settling plates and Reyniers samplers are shown in Figure 2. The low count on the settling plate at the right end of the opening suggested a drift to the left of the aerosol as it entered the high speed air shield. Obviously good protection was offered to the entire work surface.

Experiment 3:

The cabinet was turned off and a Schoeffel generator was operated for 10 minutes. The generator was located under the laboratory's supply air diffuser to provide an aerosol throughout the room. Eighteen settling plates uniformly distributed on the work surface and two Reyniers plates outside the cabinet were all TNTC.

Experiment 4:

With the cabinet blowers operating an aerosol similar to that in Experiment 3 was generated in the laboratory. During the last 5 minutes of aerosolization the door to the laboratory was opened and closed 11 times at 30 second intervals. The results are shown in Figure 3. It was demonstrated that a few microorganisms penetrated the cabinet work area and settled on the work surface as far back as the last row of settling plates. Since even the directional aerosol used in Experiment 2 did not penetrate the work area it was concluded that the penetration of the non-directional aerosol in this experiment was due to air disturbances caused by the opening and closing of the laboratory door.

Experiment 5:

An aerosol similar to that in Experiments 3 and 4 was generated in the laboratory. During the last five minutes of aerosolization a technician in protective clothing and mask walked past the front of the cabinet 11 times at 30 second intervals. The results are shown in Figure 4. Again it was demonstrated that air disturbances resulted in microorganisms penetrating the work area and settling even on the back row of plates.

Experiment 6:

An aerosol similar to that in Experiments 3-5 was generated in the laboratory. During the last 5 minutes of aerosolization a technician in protective clothing and mask sat at the cabinet and moved his hands from outside the cabinet to a position over each settling plate on the work surface several times. The results of this experiment are presented in Figure 5. In spite of what was expected to be a greater disturbing effect on the high speed air barrier than the procedures used in Experiments 4 and 5 less contamination penetrated the work area and deposited on plates.

Experiments 7 through 12:

To determine the vertical distribution of the contamination penetrating the work space as a result of door and personnel movements a series of experiments similar to Experiments 4-6 were conducted. Aerosolization was similar to previous experiments but samples were collected only at the center of the work area at heights of 1-3/4", 4-7/8" and 8" above the work surface. Both a sieve sampler drawing 1 cfm and an agar settling plate were mounted 4" apart at each sampling height. After the aerosol was established the sieve samplers were operated and settling plates were exposed during the 5 minute period when door and personnel movements were taking place. Experiment 7 involved 11 door movements at 30 second intervals and Experiment 9 was a repeat of this experiment. Experiment 8 involved 11 walk-bys at 30 second intervals and Experiment 10 was a repeat of this experiment. For Experiments 11 and 12 the glove port attachment was placed over the bench opening and the door movement and walking challenges respectively were repeated. The results of these experiments are presented in Table 1. With the exception of Experiment 9 contamination was detected in the work space during each challenge. It was also noted that, in general, contamination levels were lower at the 8" height than at the lower levels suggesting that those organisms penetrating the work space were concentrated near the work surface as they flowed to the exhaust ports.

Experiment 13:

The first 12 experiments were concerned with the ability of the cabinet to protect the work space from aerosolized contamination outside the cabinet. Beginning with Experiment 13 an effort was made to determine the ability of the cabinet to contain aerosolized contamination within the work area thus affording protection to the operator's location. In this experiment three De Vilbis nebulizers were arranged inside the cabinet in such a way as to discharge through the front opening. The nebulizer discharge ports were 7-1/2" behind the front edge of the cabinet, 4" above the work surface and equally spaced across the opening. Twenty settling plates were arranged on the work surface and three Reyniers samplers were placed outside the cabinet. The intake ports of two Reyniers samplers were located opposite the two outer nebulizers, 2-1/2" horizontally from the front edge and even vertically, with the work surface. The third Reyniers was located opposite the center nebulizer, 8" horizontally from the front edge, and 7" vertically above the work surface (even with the top of the opening). The nebulizers and Reyniers samplers were operated simultaneously for 15 minutes. The results of this experiment are shown in Figure 6. It was evident that most of the aerosol was caught in the high speed air shield and exhausted through the front exhaust port. However, some contamination was detected in each of the Reyniers samplers outside the cabinet. No contamination was detected on any of the settling plates located on the work surface.

Experiment 14:

This was a repeat of Experiment 13 with the exception of having the glove ports installed over the front opening. The results of this test are presented in Figure 7. Again most contamination was exhausted by the high speed air shield and again low levels of contamination were detected in each of the Reyniers samplers outside the cabinet. No contamination was detected on the settling plates arranged on the work surface.

Experiments 15 and 16:

One characteristic of the cabinet which was of some concern was the tendency of the temperature within the work space to rise with time as the cabinet was operated. It was found that in a laboratory with a temperature of 76 F the temperature within the cabinet reached an equilibrium temperature of 96 F after several hours of operation. In an attempt to reduce this equilibrium temperature the speed of the exhuast fan was increased thereby increasing the inflow of cooler makeup air. However, smoke tests suggested that this increased velocity of makeup air entering the front opening was disturbing the flow of the high speed air shield. To test this observation Experiments 13 and 14 were repeated under conditions of maximum exhaust fan speed. The results of these tests are presented in Figures 8 and 9 respectively. In spite of the increased flow of makeup air through the front opening contamination was still detected in each of the Reyniers samplers outside the cabinet. The front exhaust duct again appeared to be removing the bulk of the aerosol but in contrast to Experiments 13 and 14 contamination was also detected on settling plates arranged on the work surface. This contamination was particularly heavy when the glove ports were in place. These results indicate that at a high exhuast rate contaminated air was drawn from the front of the cabinet across the work surface to the rear exhuast port. Furthermore, when the glove ports were in place the size of the front opening was reduced resulting in an increased velocity of makeup air which penetrated the work space to a greater degree.

Experiments 17 through 22:

To determine the extent of cross contamination from one area of the work surface to other areas of the work surface a series of tests was performed in which a non-directional aerosol (Schoeffel) was generated 8-1/2" above the work surface for 3 minutes at each of three different locations. The pattern of deposition on the work surface was detected using the usual arrangement of settling plates. Two tests were performed with the generator at each location, one with glove ports off and one with glove ports installed. The results of these experiments are presented in Figures 10 through 15. From these results it was concluded that contamination generated on the right side of the work space remained on the right side although spreading to both the front and rear of the work surface was apparent. Contamination generated at the center of the work space spread not only to the front and rear but drifted slightly to the left. Contamination generated on the left of the work space was confined to the left side but did spread to the front and rear. The presence or absence of glove ports made no observable difference in these tests which were performed with the exhuast fan operating at a nominal rate.

Experiment 23:

This experiment was designed to test the effectiveness of the high speed air shield in preventing aerosolized contamination in the work operator were withdrawn from the work space. A non-directional aerosol was generated 8-1/2" above the nter of the work surface. Two Reyniers samplers were located outside the cabinet with the intake ports 2-1/2" from the front edge of the cabinet and 3-1/2" above the level of the work surface in positions opposite the location of the glove port openings. An operator with bare hands and arms was seated at the cabinet and at 15 second intervals took a tube from outside the cabinet in his left hand, placed both hands into the work space, transferred the tube to his right hand and withdrew both hands from the cabinet. After 20 tubes were handled in this manner the sampler under the left hand had collected 207 viable particles and the sampler under the right hand had collected 573 viable particles. The process was repeated moving the tubes from right to left and the right and left counts were 183 and 369 viable particles respectively. This indicated that contamination was in fact withdrawn from the cabinet and that the hand holding the tube withdrew more contamination than did the empty hand. Both procedures were again repeated with the glove ports in place. The increased velocity of air flowing in through the glove ports apparently reduced the level of withdrawn contamination since in moving the tubes from left to right the counts under the left and right hands were 18 and 39 viable particles respectively. Moving tubes from right to left resulted in counts under the right and left hands of 50 and 56 viable particles respectively.

Experiment 24:

To determine whether personnel walking past the cabinet when aerosolized contamination was present in the cabinet would result in contamination leaving the cabinet an aerosol was generated as in Experiment 23 and a technician walked past the front of the cabinet as in previous experiments.

Reyniers samplers were located as in Experiment 23 and after 11 passes at 30 second intervals one viable particle was found on the left sample and 3 particles on the right sample. The experiment was repeated with the glove ports in place and the left and right counts were 1 and 0 viable particles respectively.

Experiment 25:

Experiment 24 was repeated with the opening and closing of the laboratory door substituted for the walking technician. With glove ports off, after 11 door movements at 30 second intervals, the left sampler had collected 340 viable particles and the right sampler 92 viable particles. The experiment was repeated with the glove ports in place and no viable particles were detected on either sample.

Experiment 26:

This was the only experiment conducted with the glove ports in place and gloves mounted on the glove ports. The purpose was to determine whether aerosolized contamination within the cabinet would escape into the laboratory in the event of a power failure. An aerosol was generated as in Experiment 25 and two Reyniers samplers were located as in Experiment 25. While the cabinet blowers were operating no contamination was detected on either sampler. However, within 3 minutes after turning off the blowers both samples were TNTC. Since the Schoeffel generator did not raise the pressure within the work space this contamination must be attributed to diffusion leakage unless the supply blower maintains a positive pressure longer than the exhaust blower maintains a negative pressure.

The results of these 26 experiments were, for the most part, self-interpreting. Using extremely concentrated aerosols it was demonstrated that under certain commonly occurring circumstances contamination both penetrated the work space from outside the cabinet and escaped from the work space into the area occupied by the operator. In view of the unrealistically high levels of contamination used in the challenge and the relatively low levels detected in the protected areas the degree of protection afforded in both directions was great when compared with performing the same operation in an open laboratory. However, if total protection of the operator is required this cabinet should not be relied upon for absolute containment.

Observations: One of the requirements for maintaining a two-way air barrier is that the high speed air stream be as stable as possible. From observations made in this laboratory the stability of the air stream was affected by the velocity of incoming makeup air. This was particularly evident when glove ports were in place. Since the velocity of incoming air is a function of the speed of the exhaust blower a more precise system for achieving the proper exhuast setting is required. Because the heat buildup inside the cabinet may be unacceptable to certain workers it would be desirable to increase the supply of makeup air. However, there is a limit as to how much makeup air can enter the front opening without disturbing the air stream. Therefore, additional makeup air should be supplied in a controlled manner at some other point.

Several experiments demonstrated that the horizontal flow of air over the solid portion of the work surface resulted in cross-contamination within the work area. Replacement of the solid work surface with a perforated surface was proposed to keep the airflow vertical and reduce horizontal spread of contamination. To test this proposal a perforated surface was obtained from the manufacturer and a series of smoke tests were run to compare airflow patterns with those observed using the solid surface. After considerable experimentation involving attempts to attain a uniform vertical flow it was concluded that the solid top in the original design did provide optimum airflow patterns. The perforated top resulted in poor airflow patterns because of the limited plenum volume beneath the work surface.

One objection expressed by a virologist during experimental use of the cabinet was the restriction on mouth pipetting for routine tissue culture preparation caused by the limited size of the opening in the front shield while in the lowered position. The manufacturer suggested that for work in which personnel protection was not required the shield could be raised to the upper position and free access to the work area would be available. Accordingly, smoke tests were conducted with the shield raised and it was concluded that while some potential product protection was sacrificed, the work area was entirely within the flow patterns of the filtered air.

TABLE 1. PLATE COUNT RESULTS FROM EXPERIMENTS 7 THROUGH 12.

Experiment	Type of Air Disturbance	PLATE COUNTS: Settling Plates 1-3/4"	Settling Plates 4-7/8"	Settling Plates 8"	Sieve Plates 1-3/4"	Sieve Plates 4-7/8"	Sieve Plates 8"
7	door	6	2	1	TNTC	TNTC	21
8	walk	9	0	0	60	21	16
9	door	0	0	0	0	0	0
10	walk	4	0	0	29	84	0
11*	door	235	81	0	402	346	0
12*	walk	242	56	0	452	353	5

*Glove ports in place.

FIGURE 1

Location of BioQuest biological cabinet in laboratory

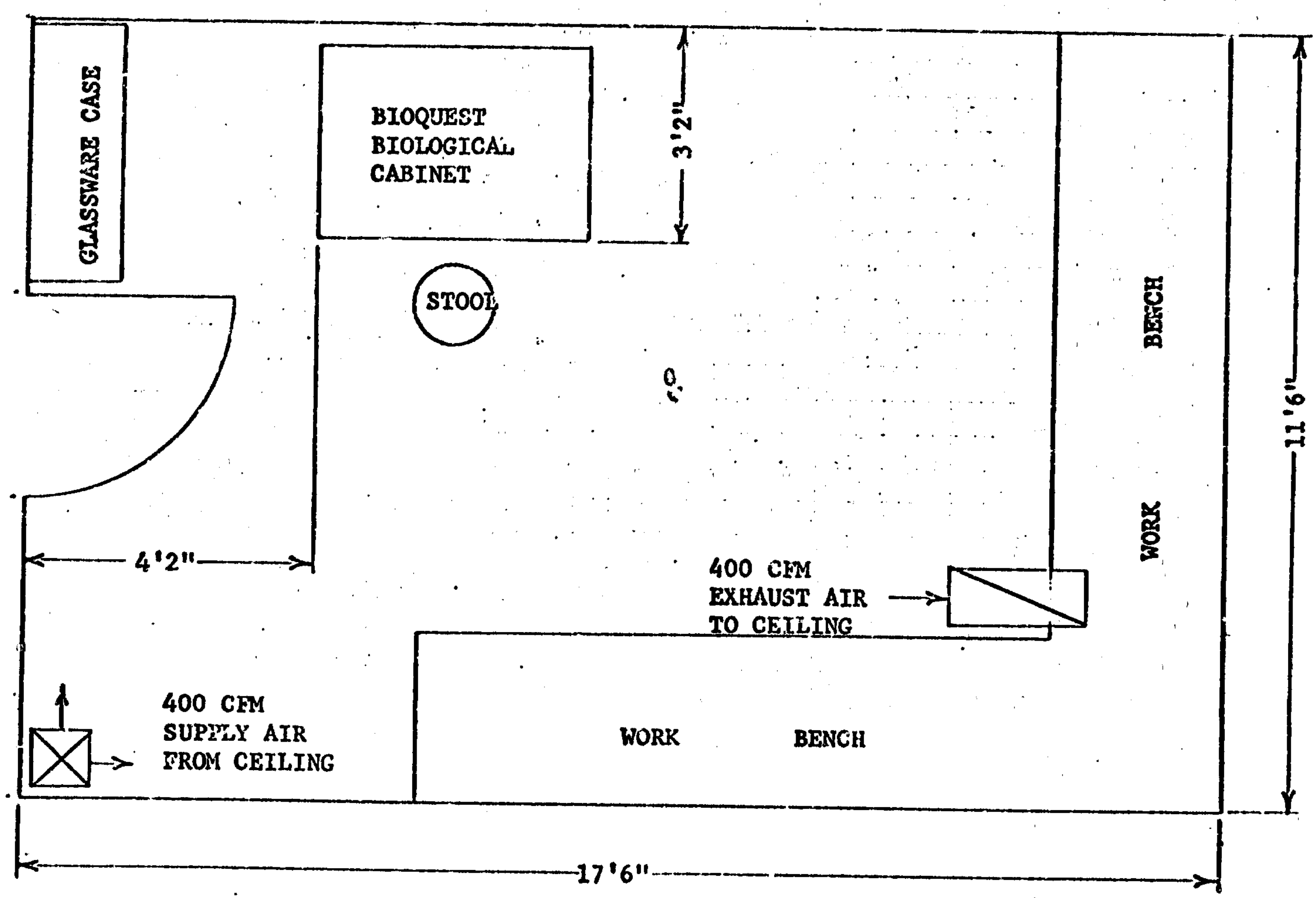
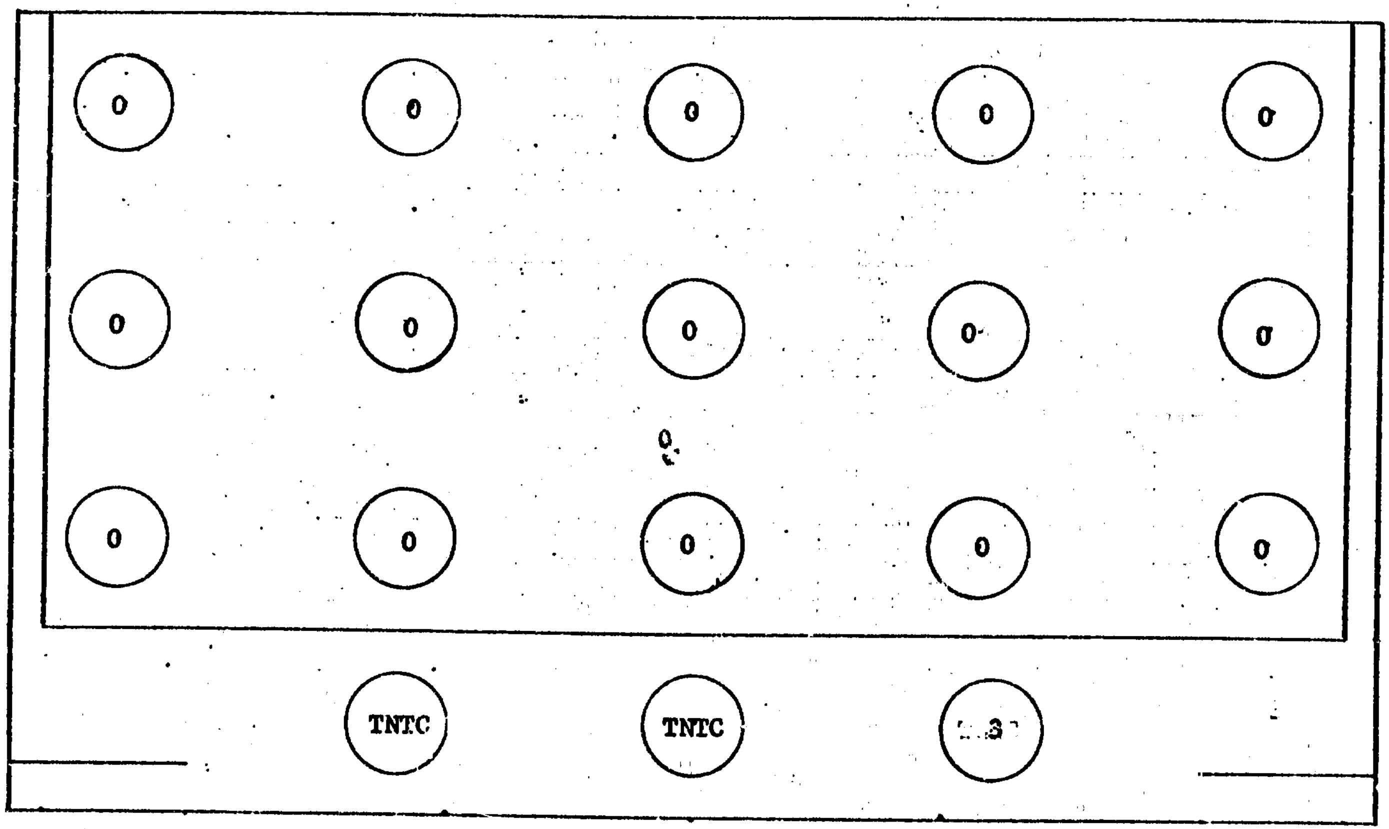


FIGURE 2

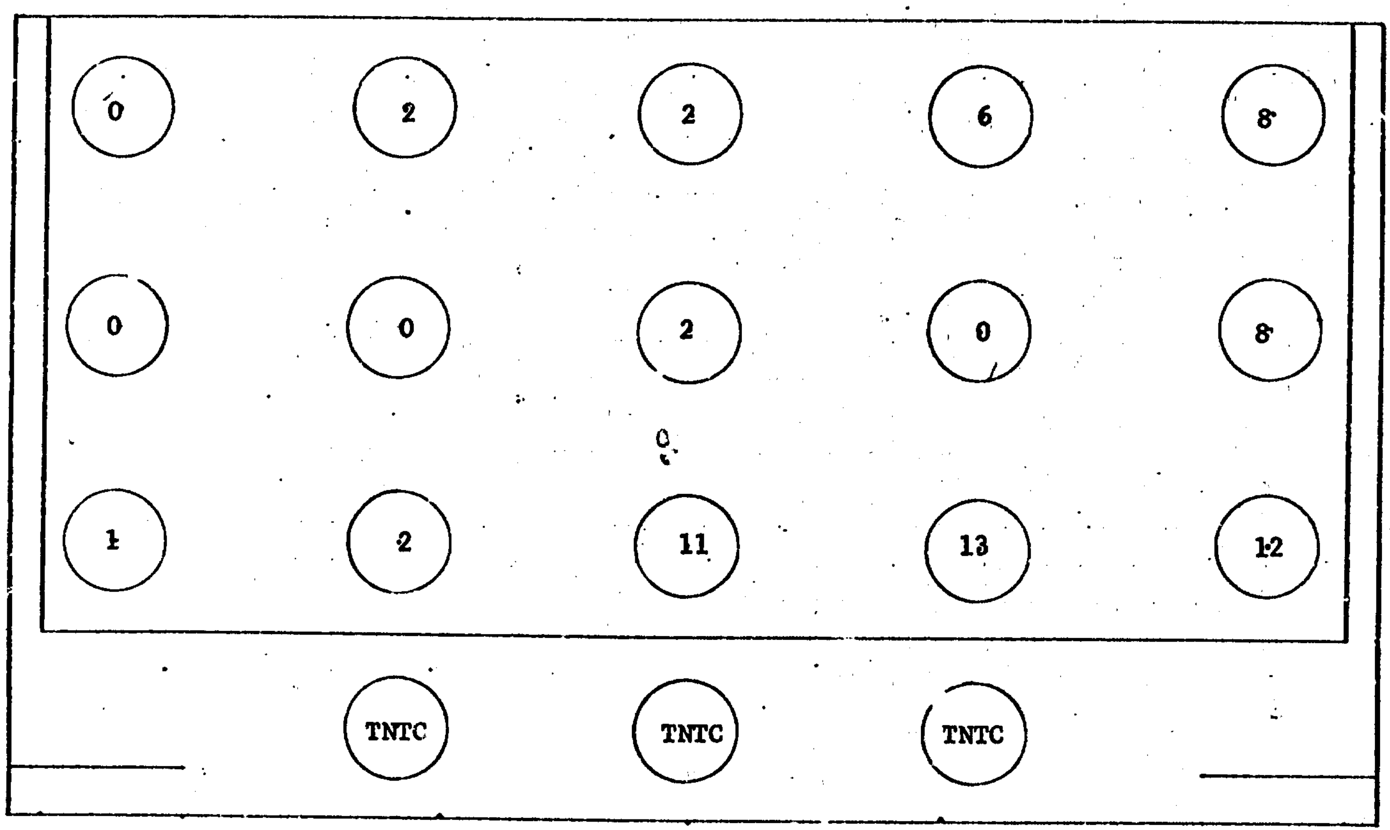
Sample location and plate counts for experiment 2



FRONT EDGE

FIGURE 3

Sample location and plate counts for experiment 4



FRONT EDGE

FIGURE 4

Sample location and plate counts for experiment 5

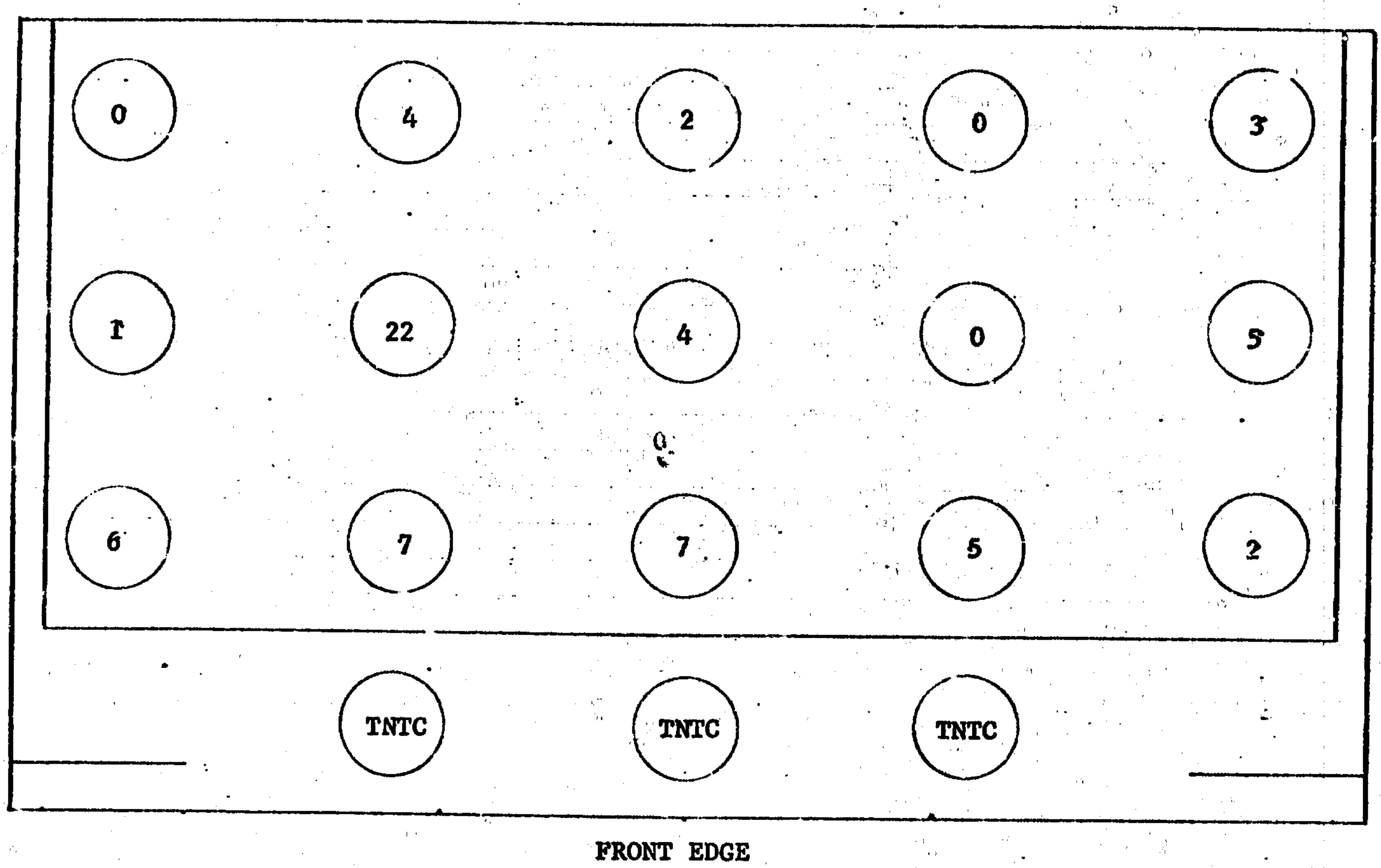


FIGURE 5

Sample location and plate counts for experiment 6

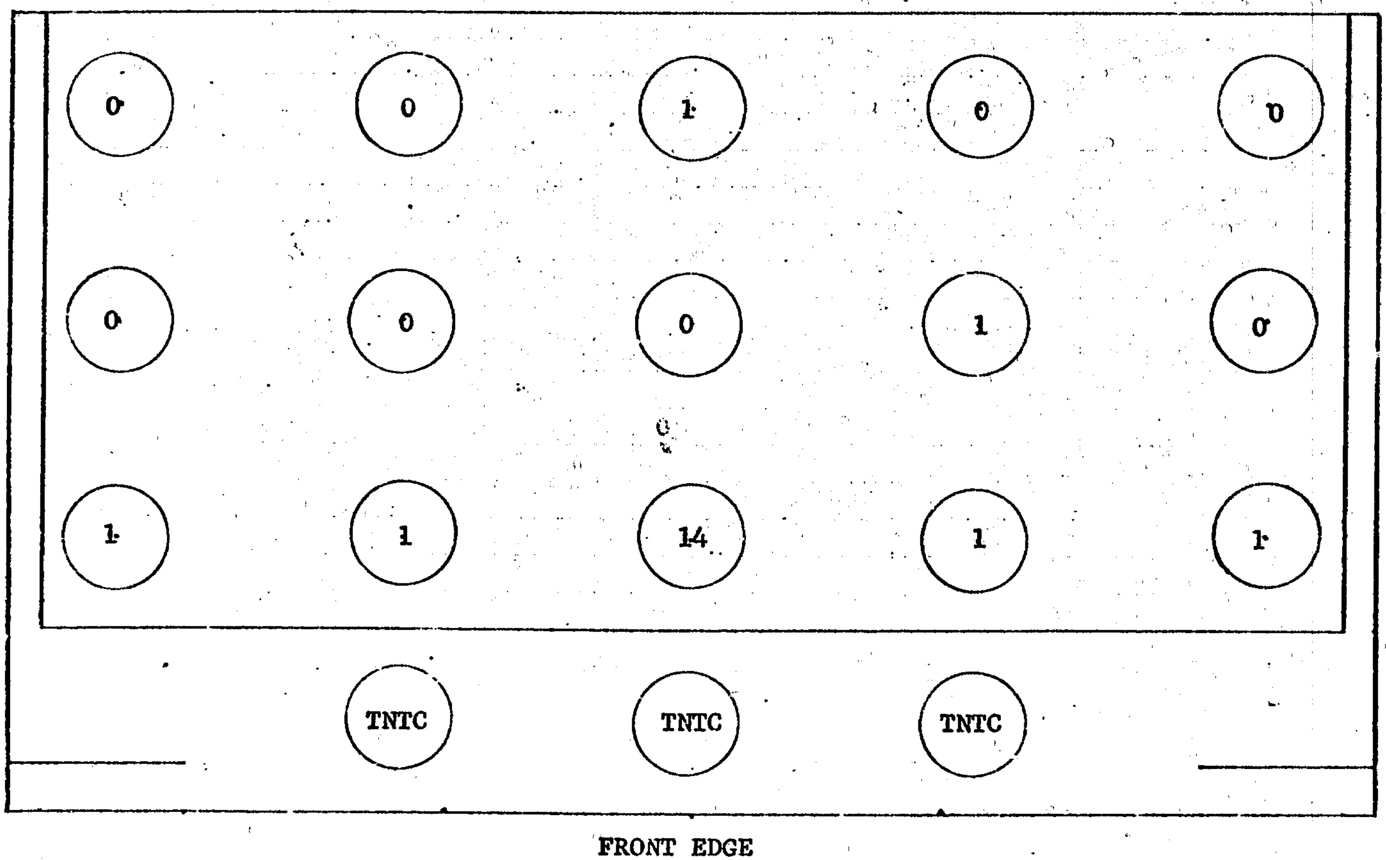


FIGURE 6

Sample location and plate counts for experiment 13

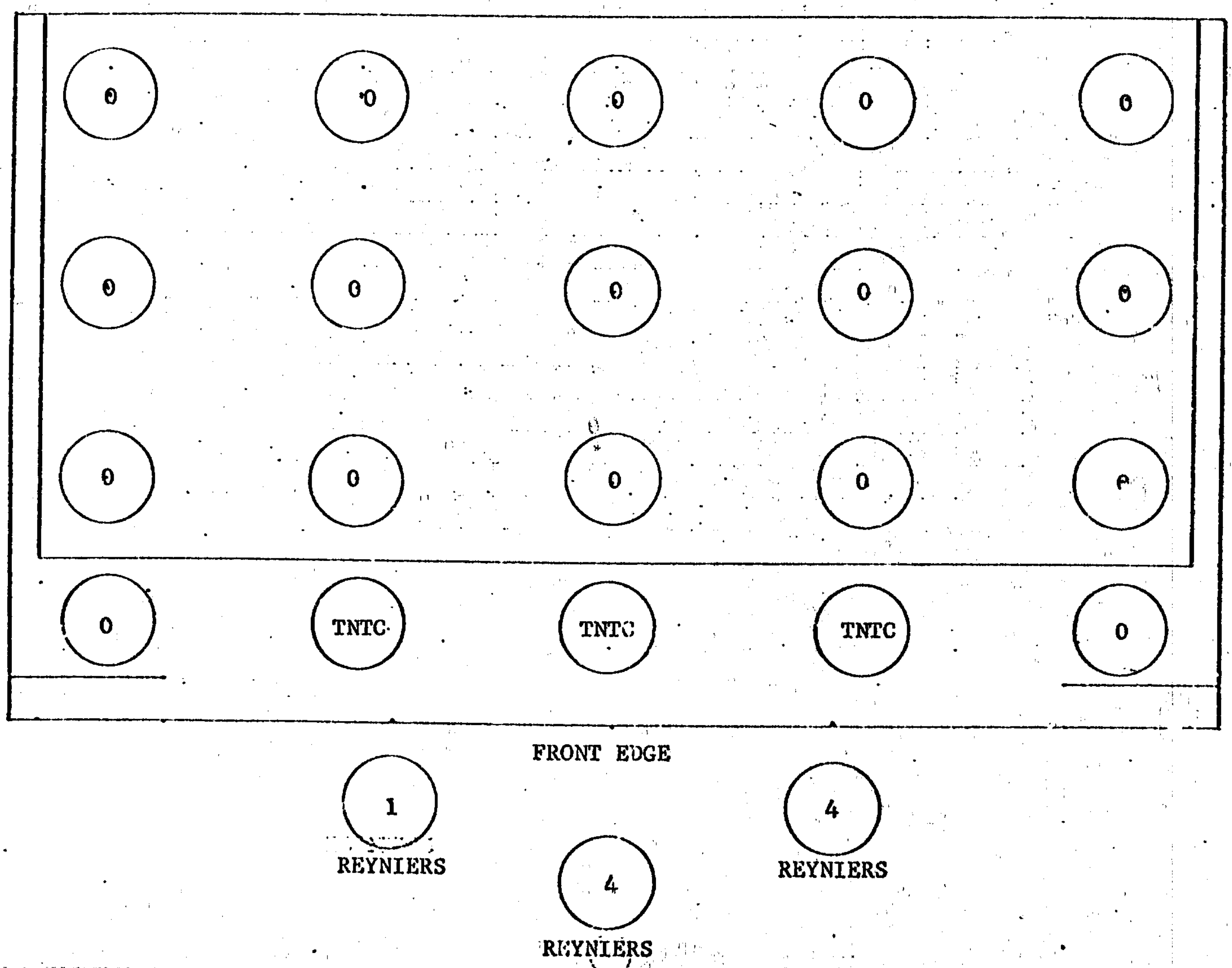


FIGURE 7

Sample location and plate counts for experiment 14

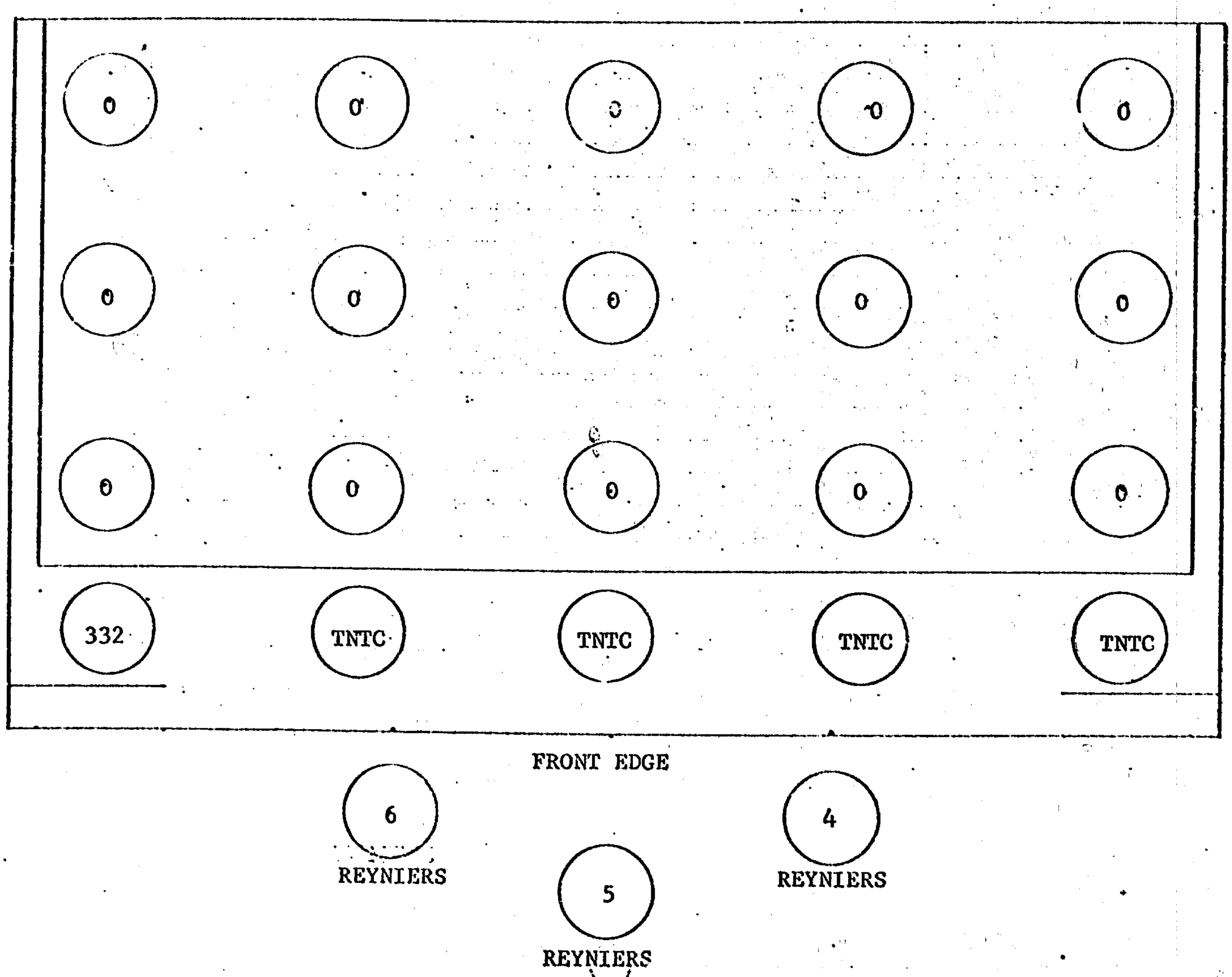


FIGURE 8

Sample location and plate counts for experiment 15

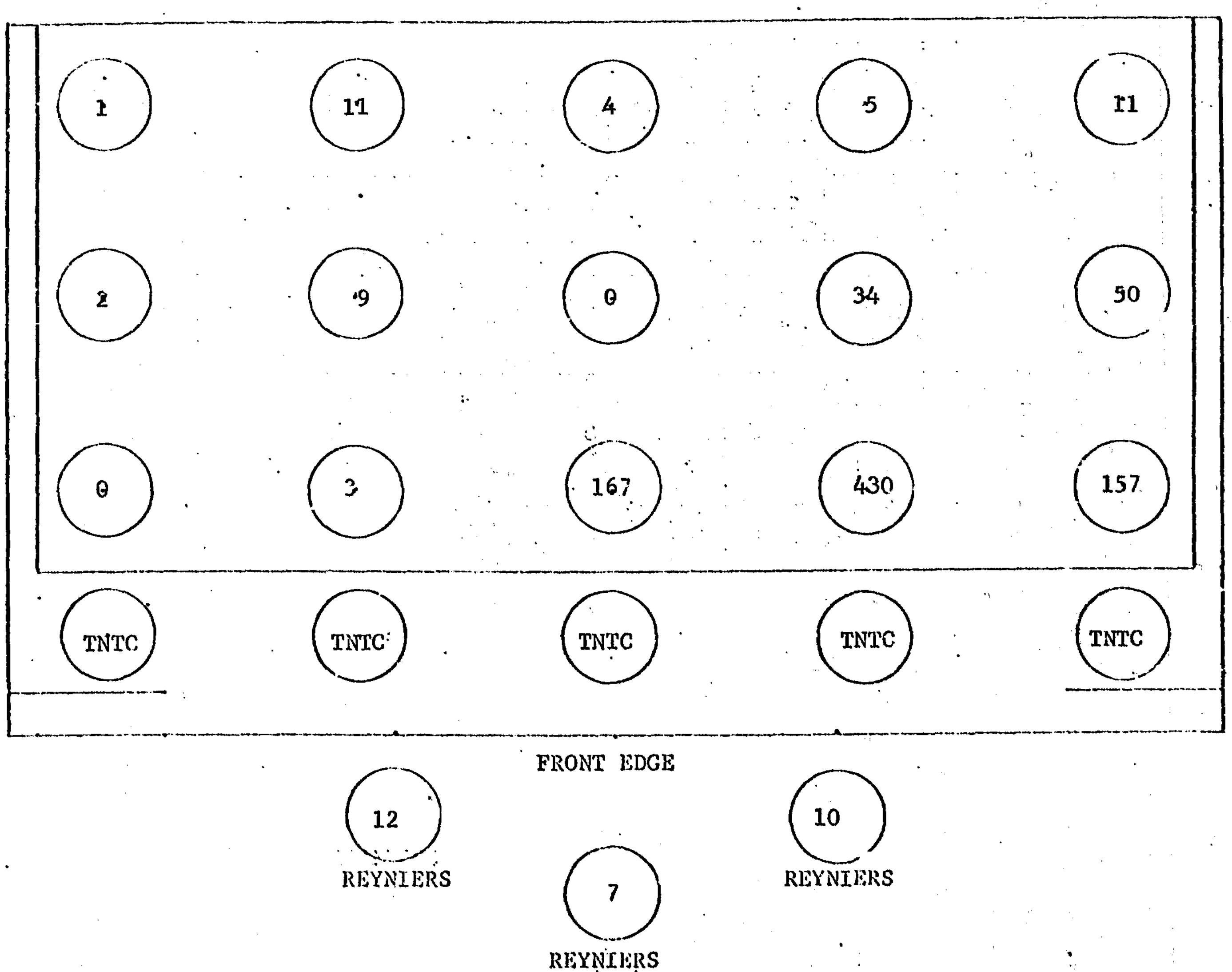


FIGURE 9

Sample location and plate counts for experiment 16

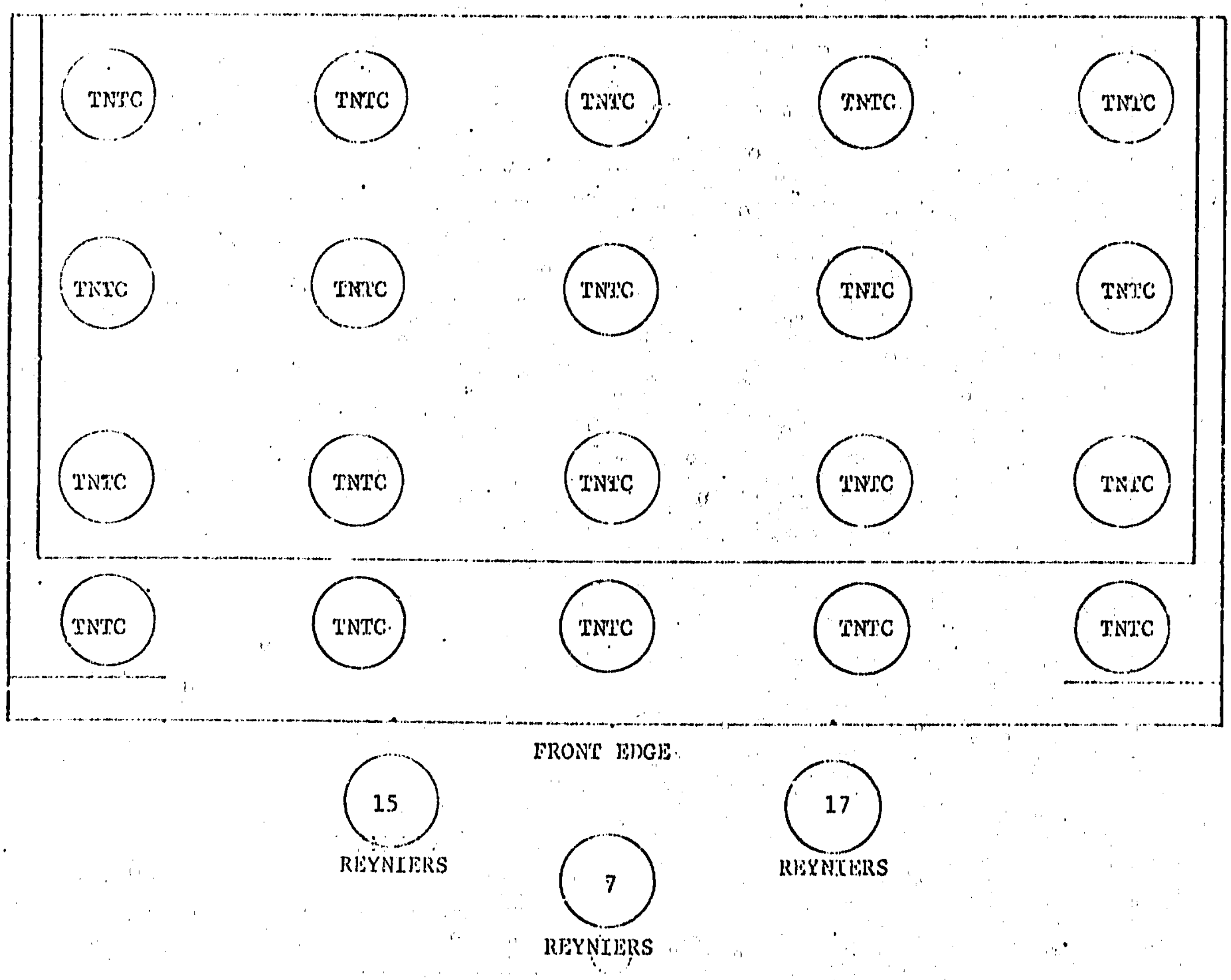


FIGURE 10

Sample location and plate counts for experiment 17

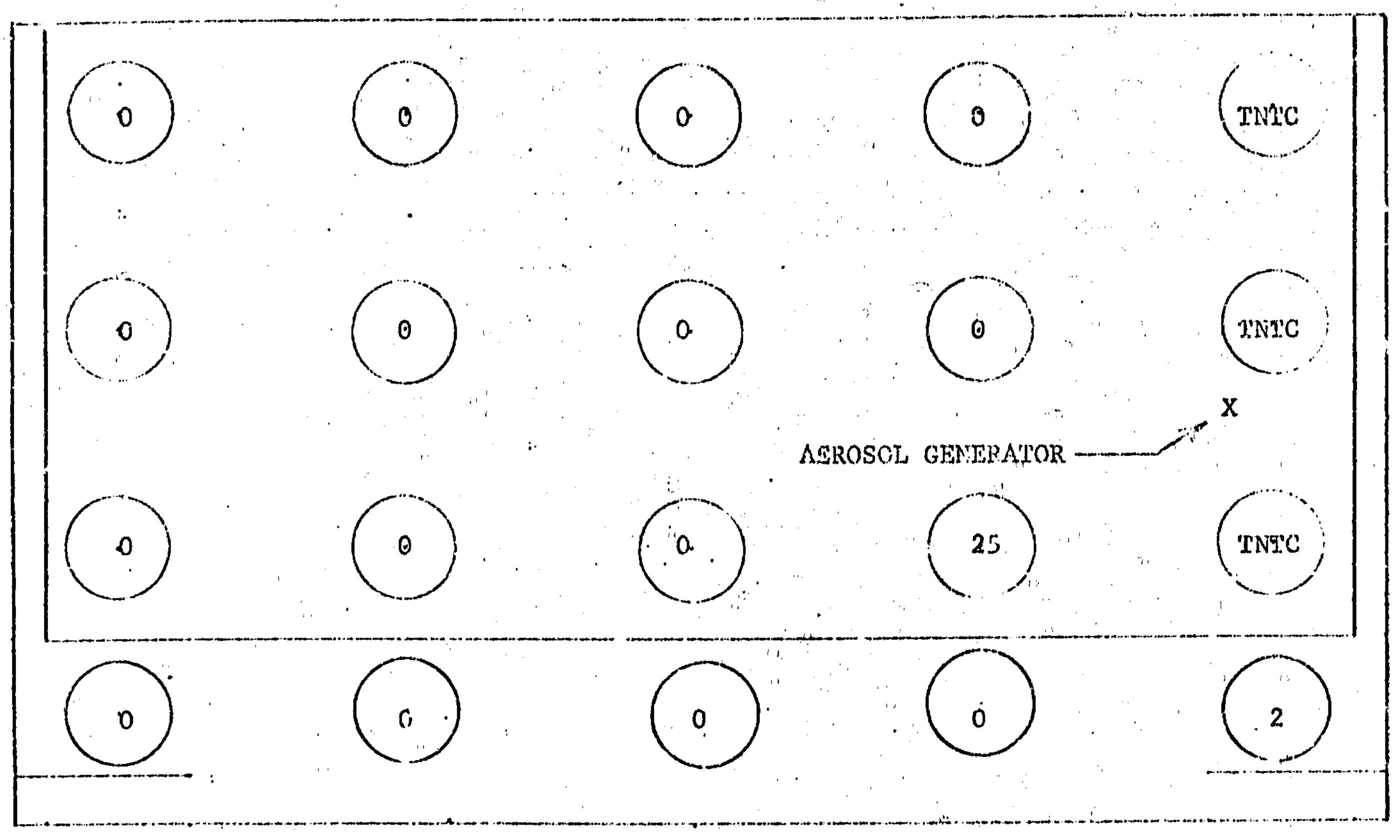


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FIGURE 11

Sample location and plate counts for experiment 18

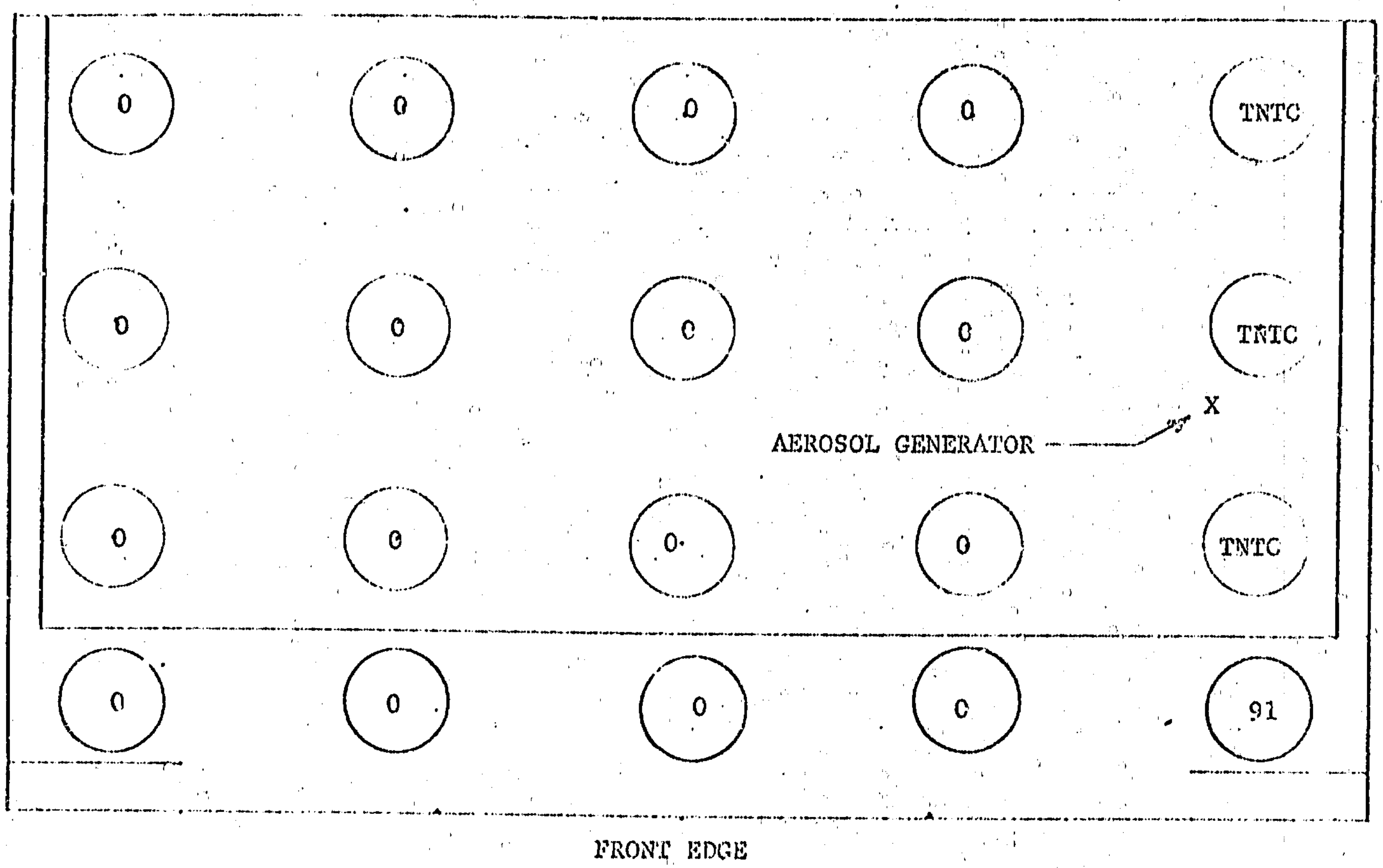

FIGURE 12

Sample location and plate counts for experiment 19

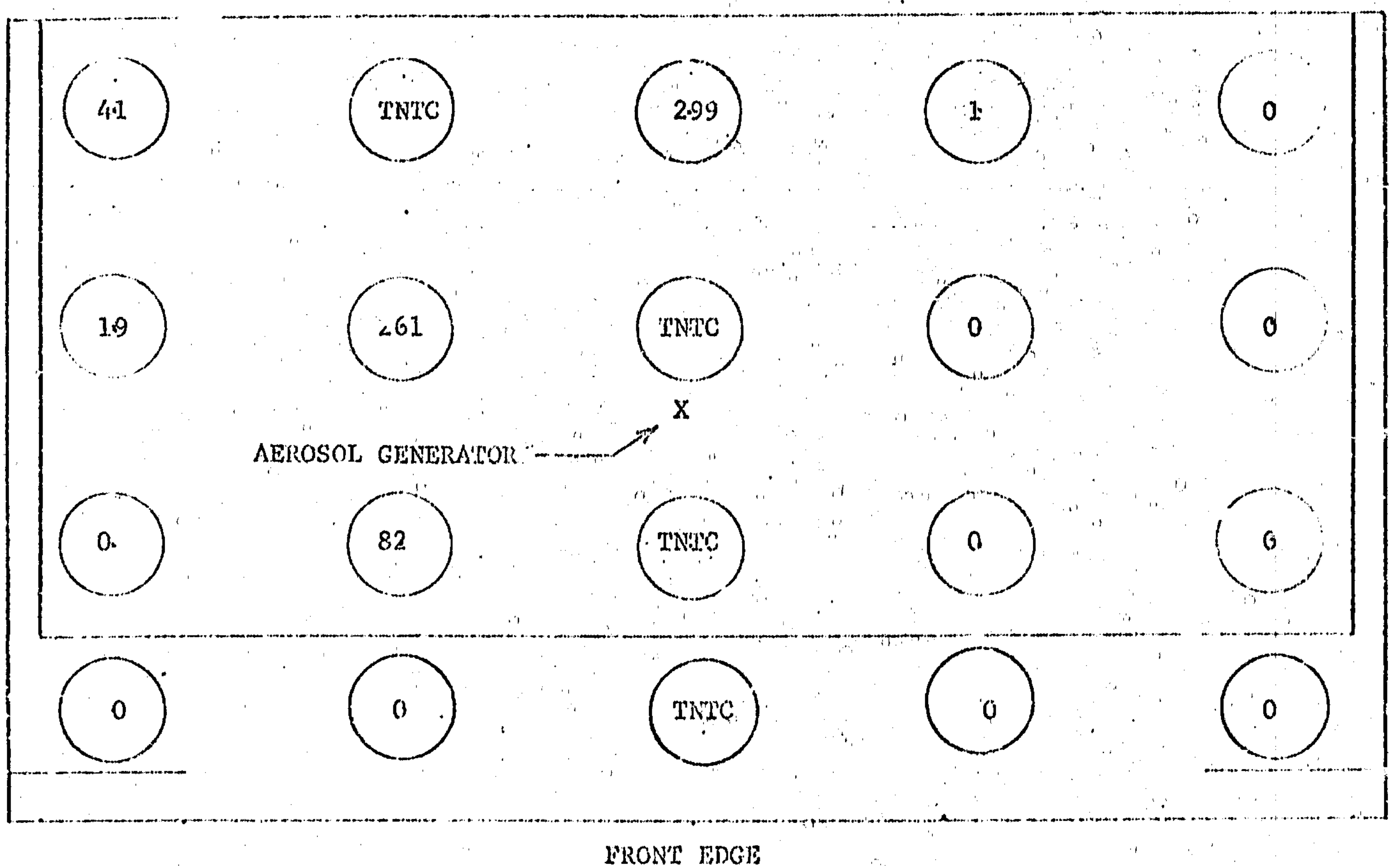

FIGURE 13

Sample location and plate counts for experiment 20

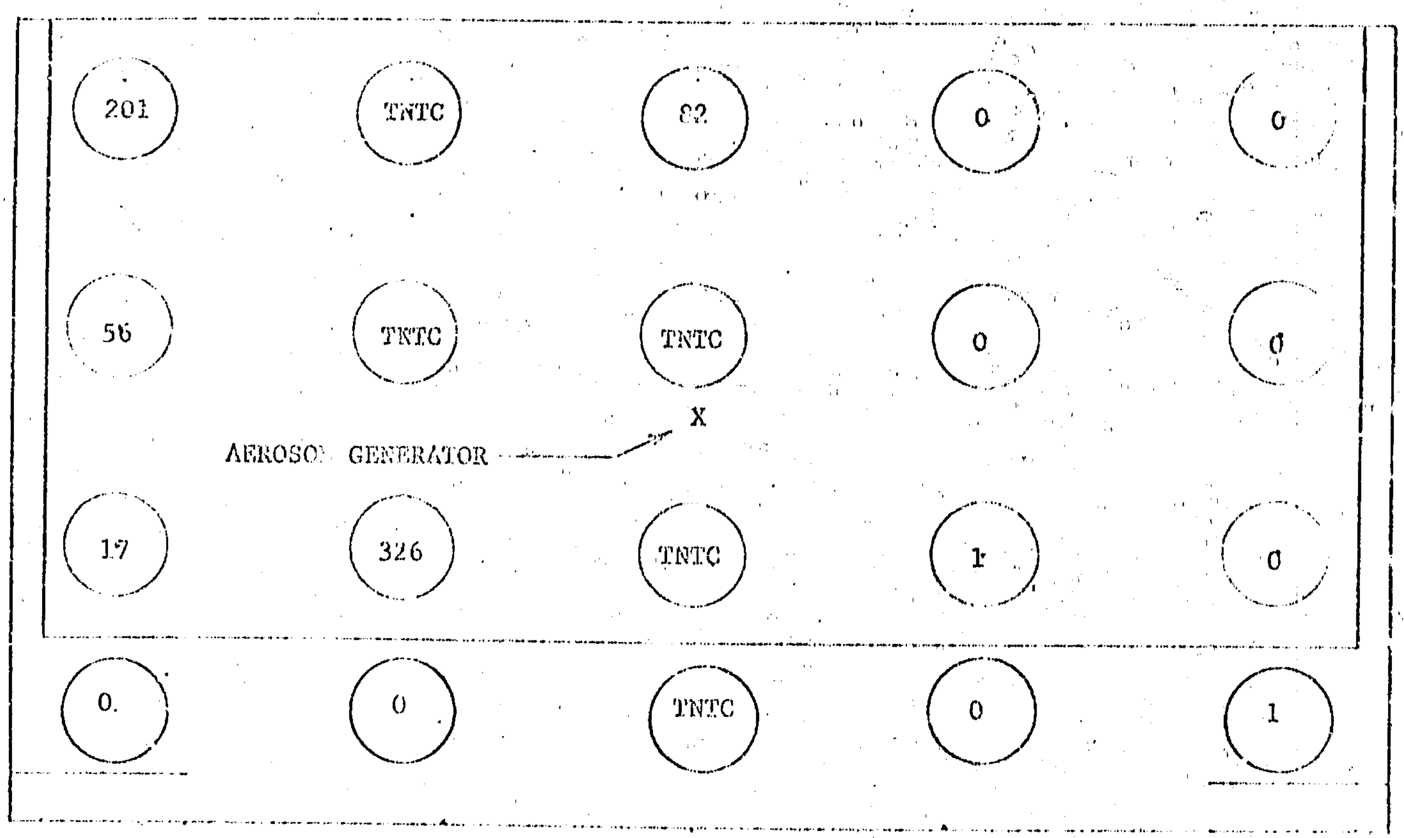

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FIGURE 14

Sample location and plate counts for experiment 21

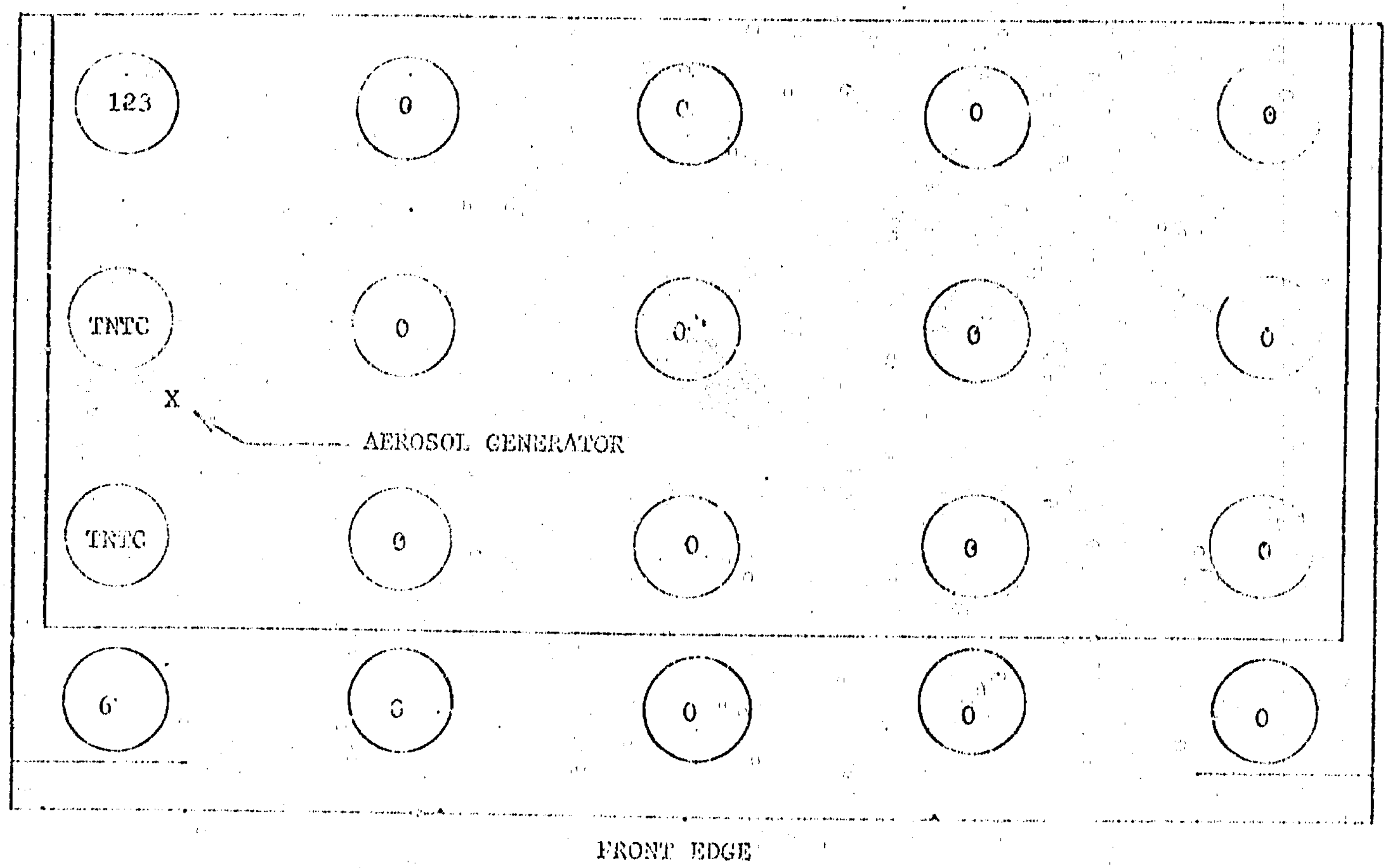
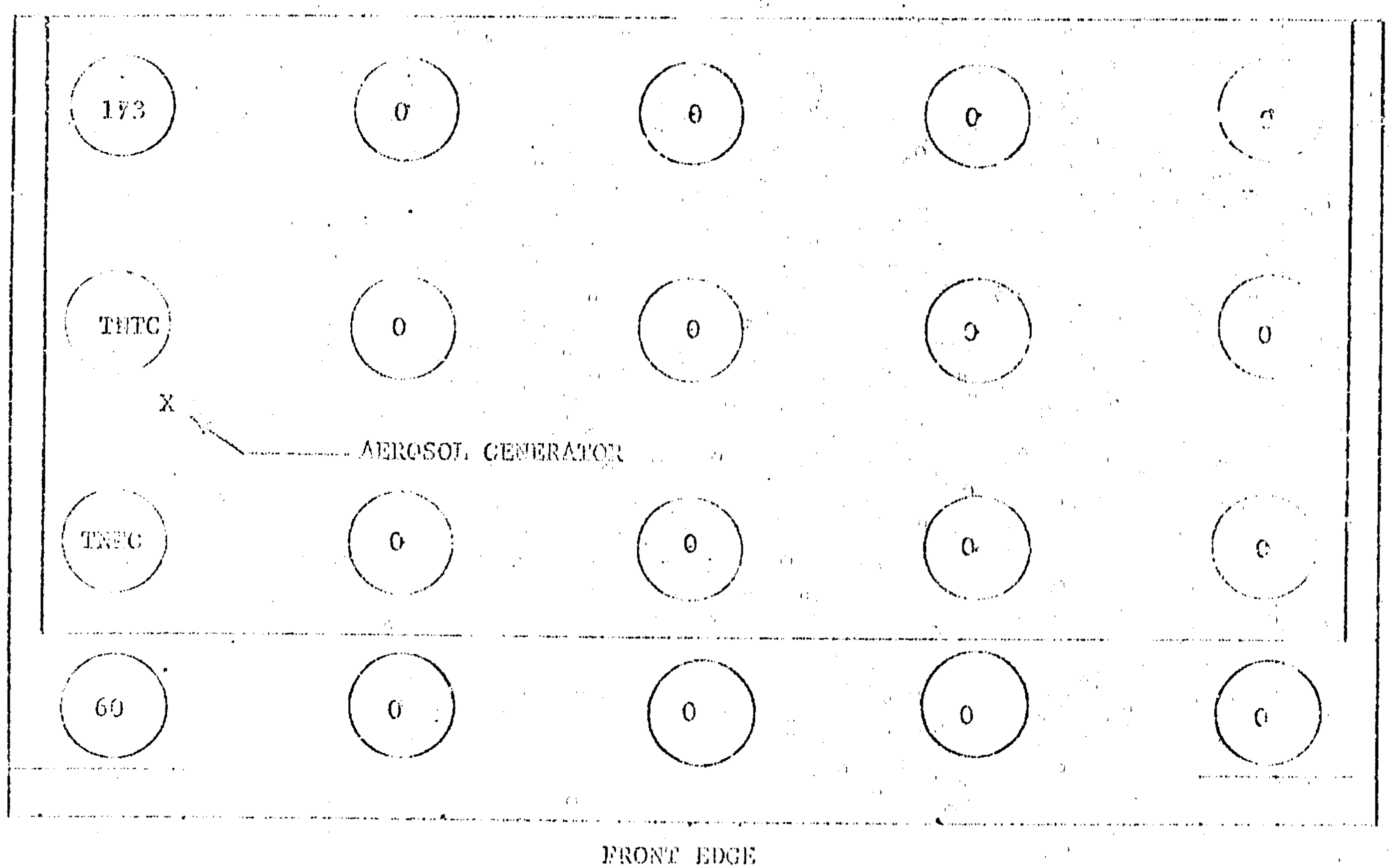


FIGURE 15

Sample location and plate counts for experiment 22



Part II: ADDENDUM

Observations and comments based on the initial evaluation of the BioQuest biological safety cabinet described in Part I were reviewed by representatives of the manufacturer and the NCDC Biohazards Officer. Discussions with the reviewers indicated several areas requiring additional experimentation. The suggested experiments were performed and the results are presented in this part of the report.

One application of the BioQuest cabinet is the provision for personnel protection against infectious agents during the performance of certain microbiological procedures. These procedures are frequently conducted in conventional biological safety cabinets which depend on the flow of room air into the cabinet to prevent aerosols in the cabinet from escaping. To determine the relative performance characteristics of the BioQuest cabinet and a biological safety cabinet installed in this laboratory a series of similar experiments were conducted in each unit.

<u>Experiments 27 and 28:</u>

These experiments were performed in the NCDC biological safety cabinet to determine whether a directional aerosol generated in the work space would escape from the cabinet into the space occupied by the operator. The experiments were similar to those reported earlier with respect to the techniques of aerosolization and sampling. The NCDC cabinet was located in a laboratory as shown in Figure 1A. Ventilation of the laboratory consisted of 250 cfm single pass filtered air. The laboratory was under negative pressure relative to space outside the door resulting in an influx of air whenever the door was opened.

The opening to the cabinet work space was 66 x 8-1/2" and the mean velocity of air through this opening was 65 fpm, which was within the recommended range of 50-75 fpm. Smoke tests indicated no disturbance of the air entering the cabinet as a result of air currents from room ventilation. Three DeVilbis nebulizers were arranged inside the cabinet in such a way as to discharge through the front opening. The nebulizer discharge ports were 7-1/2" behind the front edge of the cabinet, 4" above the work surface and equally spaced 8" apart. Eight settling plates were arranged on the work surface and three Reyniers samplers were placed outside the cabinet. The intake ports of two Reyniers samplers were located opposite the two outer nebulizers, 2-1/2" horizontally from the front edge and even vertically, with the work surface. The third Reyniers was located opposite the center nebulizer, 8" horizontally from the front edge and even vertically with the top of the opening. After operating the Reyniers samplers for a 2-minute background period the nebulizer on the right was operated along with the Reyniers for 5 minutes. This was followed by a second 5-minute background period during which only the Reyniers were operated. The middle nebulizer was then operated for 5 minutes followed by a 5-minute background period. Finally, the left nebulizer was operated for 5 minutes. The results of Experiment 27 are presented in Figures 2A, 3A, and 4A. It was found that nebulizing in each location resulted in some viable particles escaping from the cabinet and being detected in the Reyniers samplers. Fewer viable particles were found in the middle sampler than in the left and right samplers. This was probably due to the higher elevation of the sampler and its greater distance from the cabinet opening. All settling plates in the work surface had colony counts which were TNTC (too numerous to count) as would be expected from the air flow patterns in the cabinet.

Experiment 28 was a replicate of Experiment 27. The results are presented in Figures 5A, 6A, and 7A and were comparable to the results in Experiment 27.

Experiment 29:

This experiment was conducted in the NCDC biological safety cabinet and was similar to Experiments 27 and 28 with two exceptions. The major difference was that instead of static conditions existing in the room during the periods of aerosolization a technician walked past the front of the cabinet, at a distance of two feet from the face of the cabinet, a total of 11 times during each 5-minute aerosolization period. A second difference was that no settling plates were placed in the cabinet because of the certainty that they would be TNTC. The results of the experiment are presented in Table 1A. Comparison of these results with those in Experiments 27 and 28 indicated that disturbance of the airflow caused by the movement of the technician resulted in greater numbers of viable particles escaping into the operator's position. In particular, the middle Reyniers sampler located nearest the operator's breathing zone showed a dramatic increase in the number of viable particles detected.

Experiment 30:

This experiment was conducted in the NCDC biological safety cabinet and was identical to Experiment 29 with the exception that in place of the technician walking past the cabinet the door to the laboratory was opened and closed 11 times during each 5-minute aerosolization period. The results are presented in Table 2A and were similar to the results caused by the walking technician. Again, the middle sampler showed the most marked increase in plate count when compared with the results obtained with the cabinet in a static condition.

Experiment 31:

This experiment was conducted in the NCDC biological safety cabinet and was designed to test the effectiveness of the inflow of air in preventing aeroslized contamination in the work space from being transferred outside the cabinet when the hands of the operator were withdrawn from the work space. A non-directional aerosol was generated 8-1/2" above the center of the work surface. Two Reyniers samplers were located outside the cabinet with the intake ports 2-1/2" from the front edge of the cabinet and 3-1/2" above the level of the work surface in positions where the hands entering the leaving the work space would pass directly over the ports. A 10-minute period of aerosolization and sampling confirmed that the non-directional aerosol would not escape from the cabinet under static conditions. An operator with bare hands and arms was seated at the cabinet and at 15 second intervals took a tube from outside the cabinet in his left hand, placed both hands in the aerosol, transferred the tube to his right hand and withdrew both hands from the cabinet. After 20 tubes were handled in this manner the process was repeated moving the tubes from the right to the left. The entire procedure was then repeated. The mean number of viable particles per procedure detected by the sampler under the left hand was 29 while 182 viable particles were detected under the right hand. These values were considerably lower than the 576 and 756 for the left and right respectively that were reported for a similar experiment (Experiment 23) performed earlier in the BioQuest cabinet.

Experiment 32:

A question concerning the BioQuest cabinet that was not answered in the initial evaluation was whether obstruction of the peripheral exhaust vents on the work surface with laboratory items resulted in reduced efficacy of the cabinet. To investigate this factor several experiments similar to those performed in the NCDC biological safety cabinet were conducted in the BioQuest cabinet under conditions of careless overloading. Figure 8A shows the location of items on the work surface and indicates that a significant portion of the exhuast vent area is either blocked or partially obstructed. Accordingly, these experiments compare the BioQuest cabinet in a "worst case" condition with the NCDC biological safety cabinet in the optimum condition.

This particular experiment was conducted to compare the results with those from Experiment 31. The experimental set-up was identical to that used in Experiment 31. Each procedure consisted of passing 20 tubes from left to right and back again. The mean values from two such procedures were 23 viable particles detected under the left hand and 154 under the right hand. These results were remarkably similar to those from the NCDC cabinet experiment. However, they were markedly lower than the values from a similar experiment conducted in an unobstructed BioQuest cabinet. A probable explanation for the superior barrier effect in the obstructed bench is that blocking of the rear and side exhaust vents increases the velocity of air through the front vent in the region through which the hands pass as they leave the cabinet. This increased velocity results in greater removal of contamination from the hands.

Experiment 33:

This experiment was conducted in the obstructed BioQuest cabinet and was similar to Experiment 32 with the exception that glove ports were in place. The tube passing procedure was performed twice in this experiment and the mean number of viable particles per procedure detected under the left hand was 22 and under the right hand 59. These values were compared to the results from an earlier similar experiment in an unobstructed cabinet and were found to be markedly lower, a pattern similar to that in Experiment 32.

Experiments 34 and 35:

These were replicate experiments performed in the BioQuest cabinet and conducted in a manner identical to that of Experiments 27 and 28. The results of Experiment 34 are presented in Figures 9A, 10A, and 11A and the results of Experiment 35 are presented in Figures 12A, 13A, and 14A. Except for a single extreme value in Experiment 34 the results of the two experiments were comparable. In general, the values for viable particles detected outside the BioQuest cabinet were lower than those observed in similar experiments in the NCDC cabinet. The values from settling plates inside the work area were, of course, neglibible when compared to the values from settling plates in the NCDC cabinet.

Although experimental procedures were not identical, a comparison was made of the results of these experiments with those of Experiment 13. It was noted that with the exception of one extreme value the numbers of viable particles detected outside the cabinet were comparable in all experiments suggesting that the partial obstruction of the exhaust vents did not materially affect the integrity of the air barrier.

Experiment 36:

This experiment was designed to compare the obstructed BioQuest cabinet with the unobstructed cabinet when glove ports were in place. Experimental procedures were identical to those in Experiment 14 and consisted of attempting to discharge a directional aerosol through the glove ports. The results are presented in Figure 15A and agree with the previous experiment in that partial obstruction of the exhaust vents resulted in no observable increase in the number of viable particles escaping from the cabinet.

Three conclusions appear justified by the results of the additional experiments reported here.

1. The partial obstruction of exhaust vents in the BioQuest cabinet simulated by overloading and careless placement of items within the work space did not result in a measurable degradation of the cabinet's performance in any of the tests that were conducted.
2. Directional aerosols generated within the conventional biological safety cabinet routinely escaped through the work opening. The escape of these aerosols into the area occupied by the operator was markedly enhanced by local air disturbances caused by walking past the cabinet and opening and closing the door to the room in which the cabinet was located.
3. In the comparative tests performed, personnel protection provided by the BioQuest cabinet in an obstructed configuration was equal or superior to the protection afforded by the NCDC biological safety cabinet in an optimum configuration. The BioQuest cabinet, in addition, provided dramatically superior product protection.

TABLE 1A. RESULTS OF EXPERIMENT 29 SHOWING NUMBER OF VIABLE PARTICLES DETECTED OUTSIDE NCDC BIOLOGICAL SAFETY CABINET WHEN TECHNICIAN WALKED PAST FRONT OPENING.

Reyniers Sampler Position	Viable Particles Detected on Reyniers Plates Nebulizer Position		
	Left	Center	Right
Left	345	165	230
Center	TNTC	TNTC	TNTC
Right	272	TNTC	TNTC

TABLE 2A. RESULTS OF EXPERIMENT 30 SHOWING NUMBER OF VIABLE PARTICLES DETECTED OUTSIDE NCDC BIOLOGICAL SAFETY CABINET WHEN LABORATORY DOOR WAS REPEATEDLY OPENED AND CLOSED.

Reyniers Sampler Position	Viable Particles Detected on Reyniers Plates Nebulizer Position Left	Center	Right
Left	133	266	119
Center	TNTC	294	TNTC
Right	TNTC	TNTC	189

FIGURE 1A

Location of NCDC biological safety cabinet in laboratory

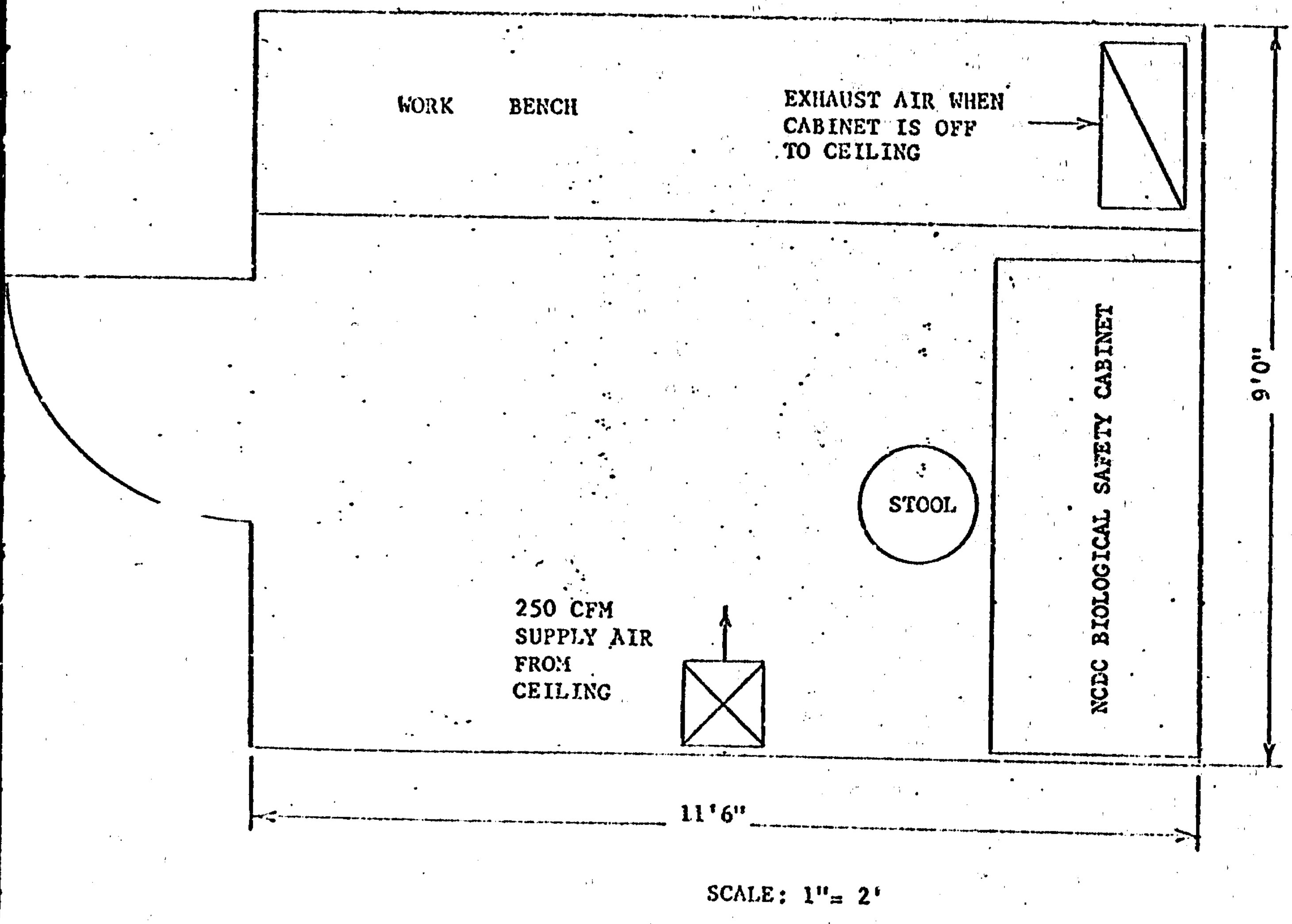


FIGURE 2A

Sample location and plate counts for experiment 27

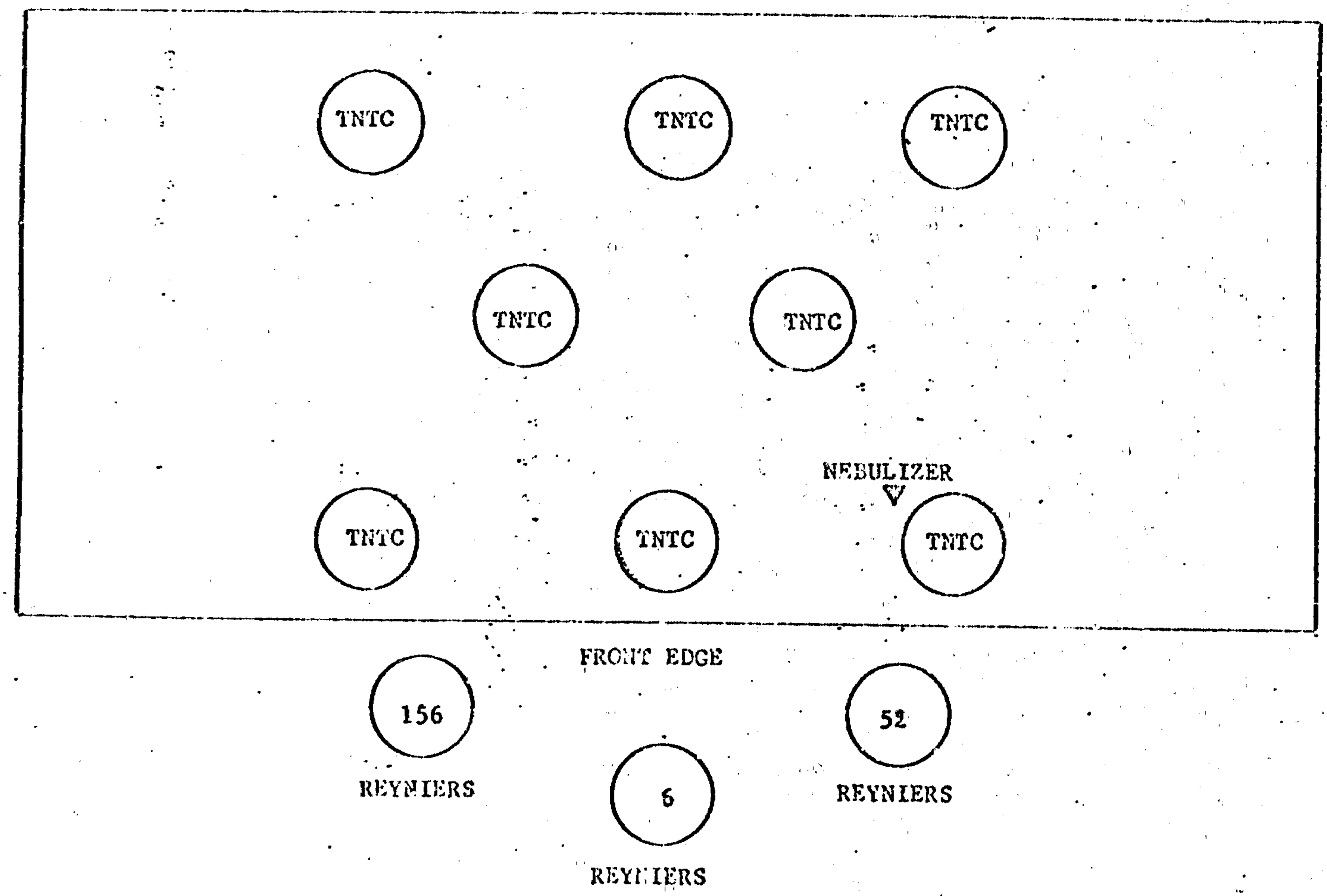


FIGURE 3A

Sample location and plate counts for experiment 27

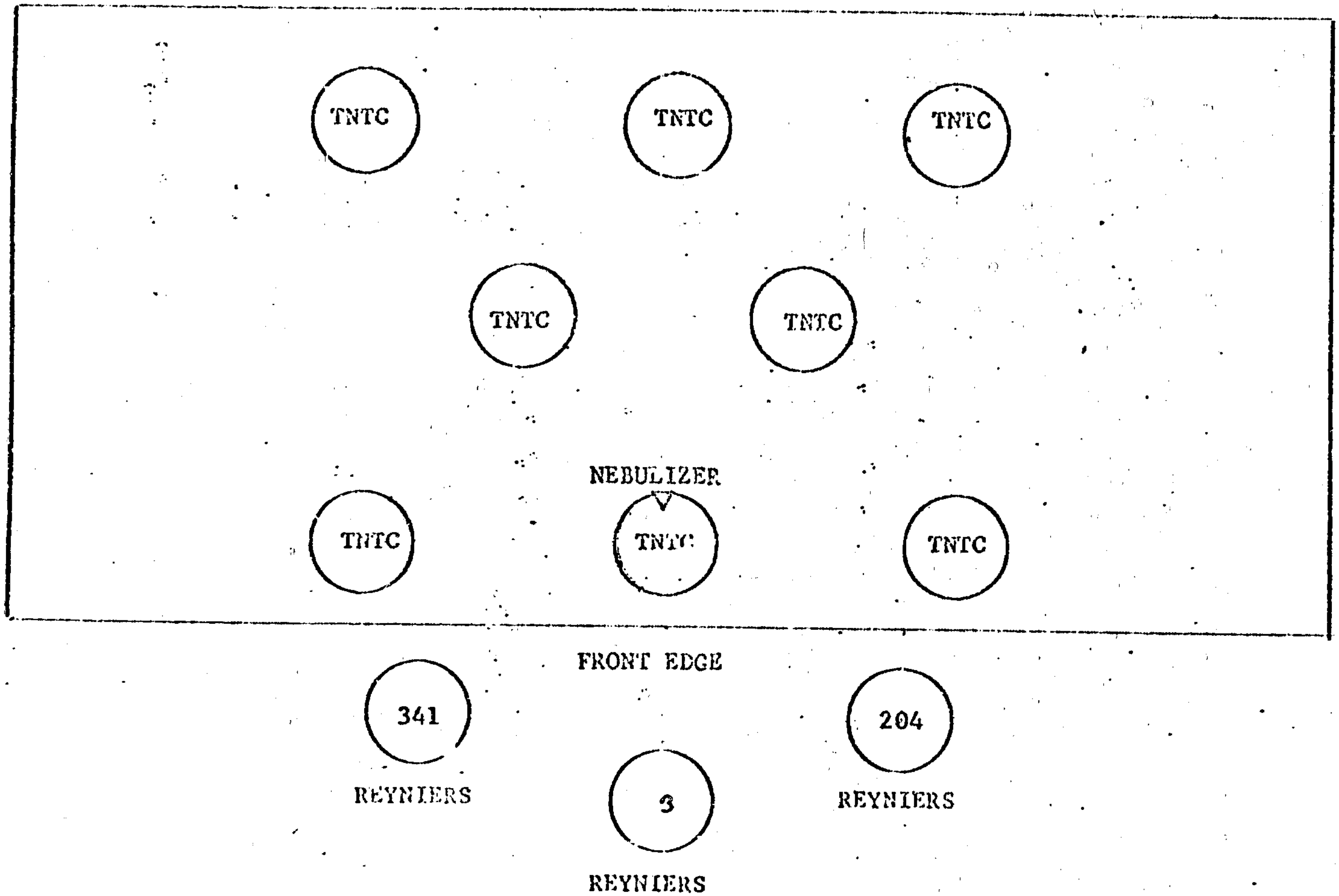


FIGURE 4A

Sample location and plate counts for experiment 27

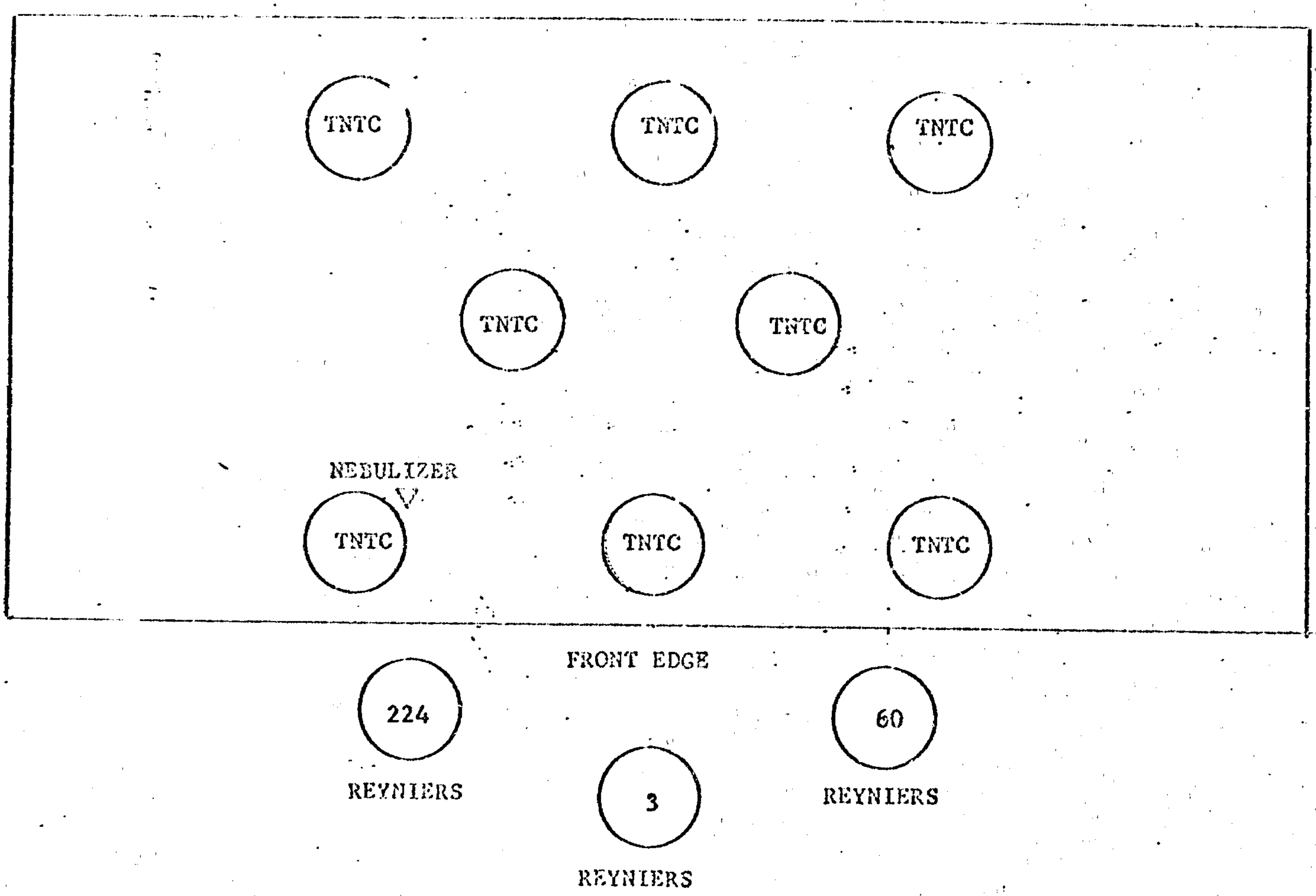


FIGURE 5A

Sample location and plate counts for experiment 28

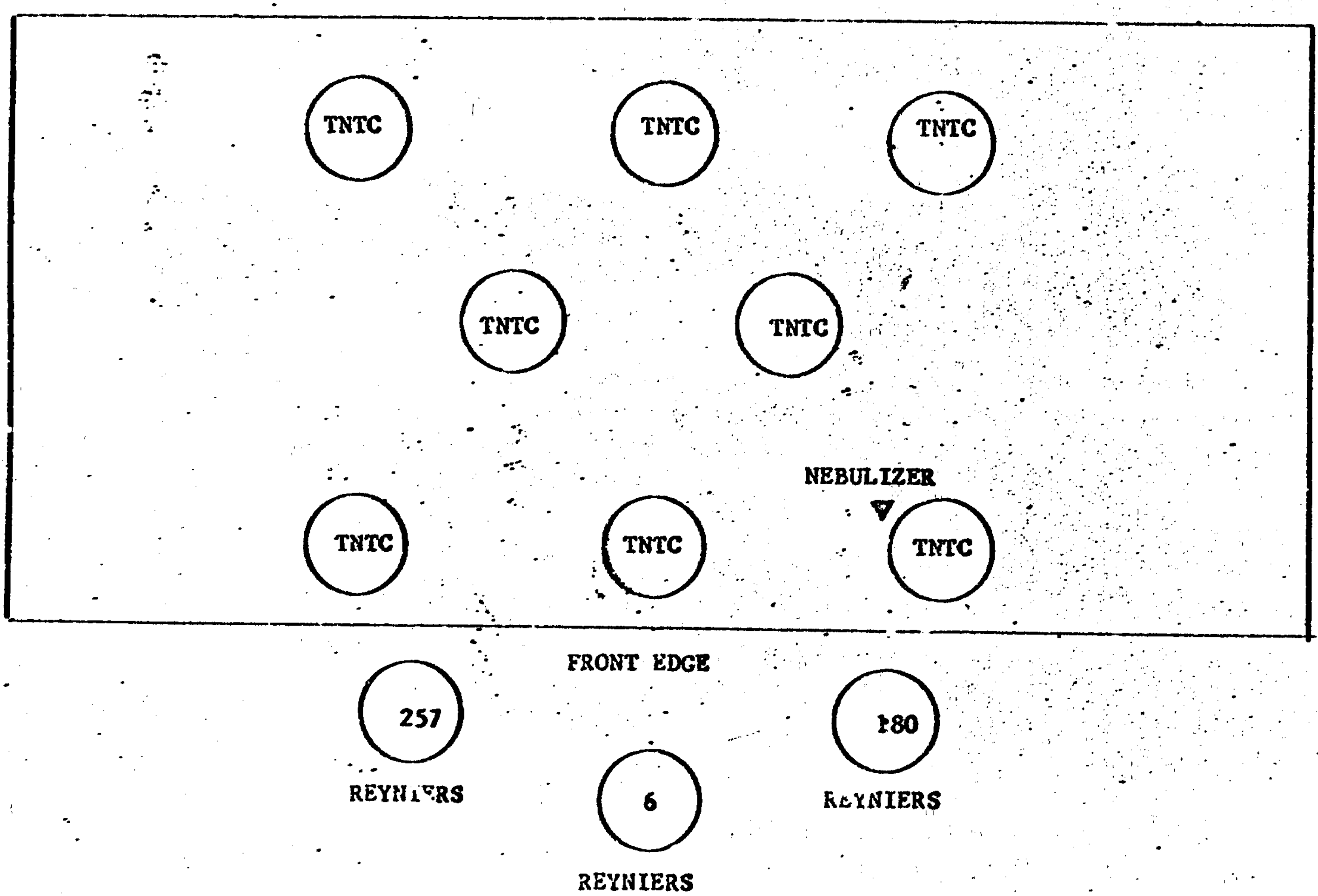


FIGURE 6A

Sample location and plate counts for experiment 28

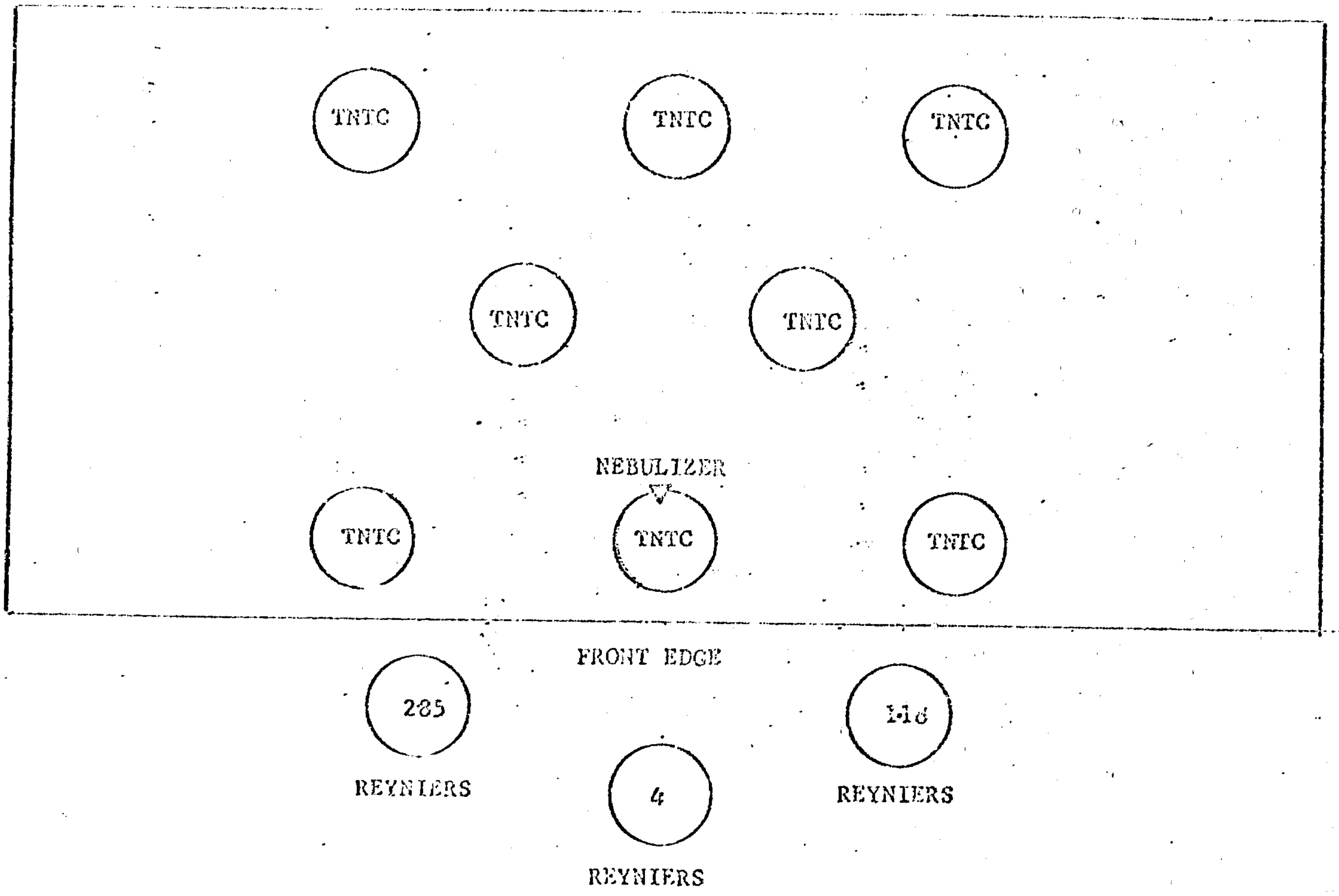


FIGURE 7A

Sample location and plate counts for experiment 28

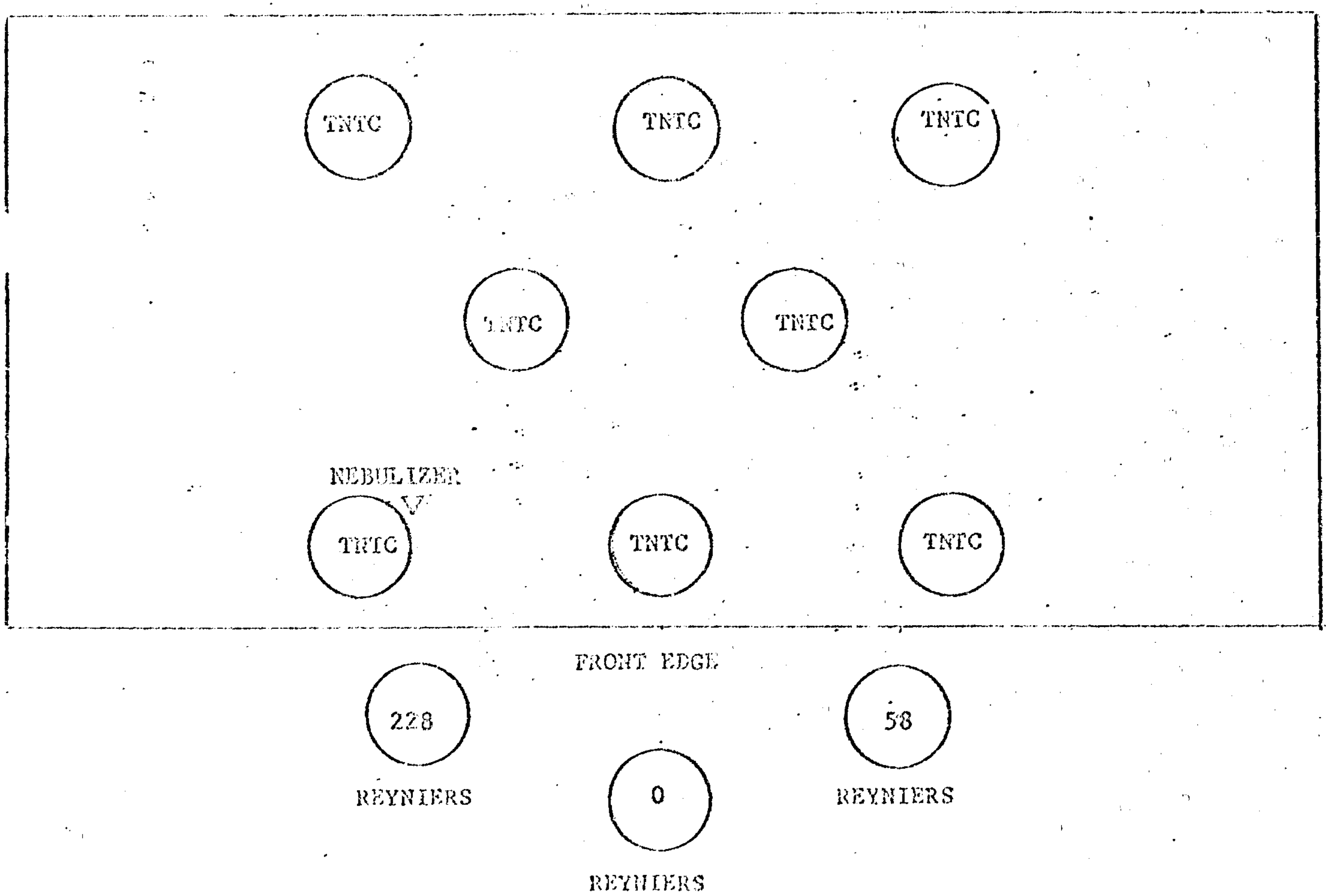
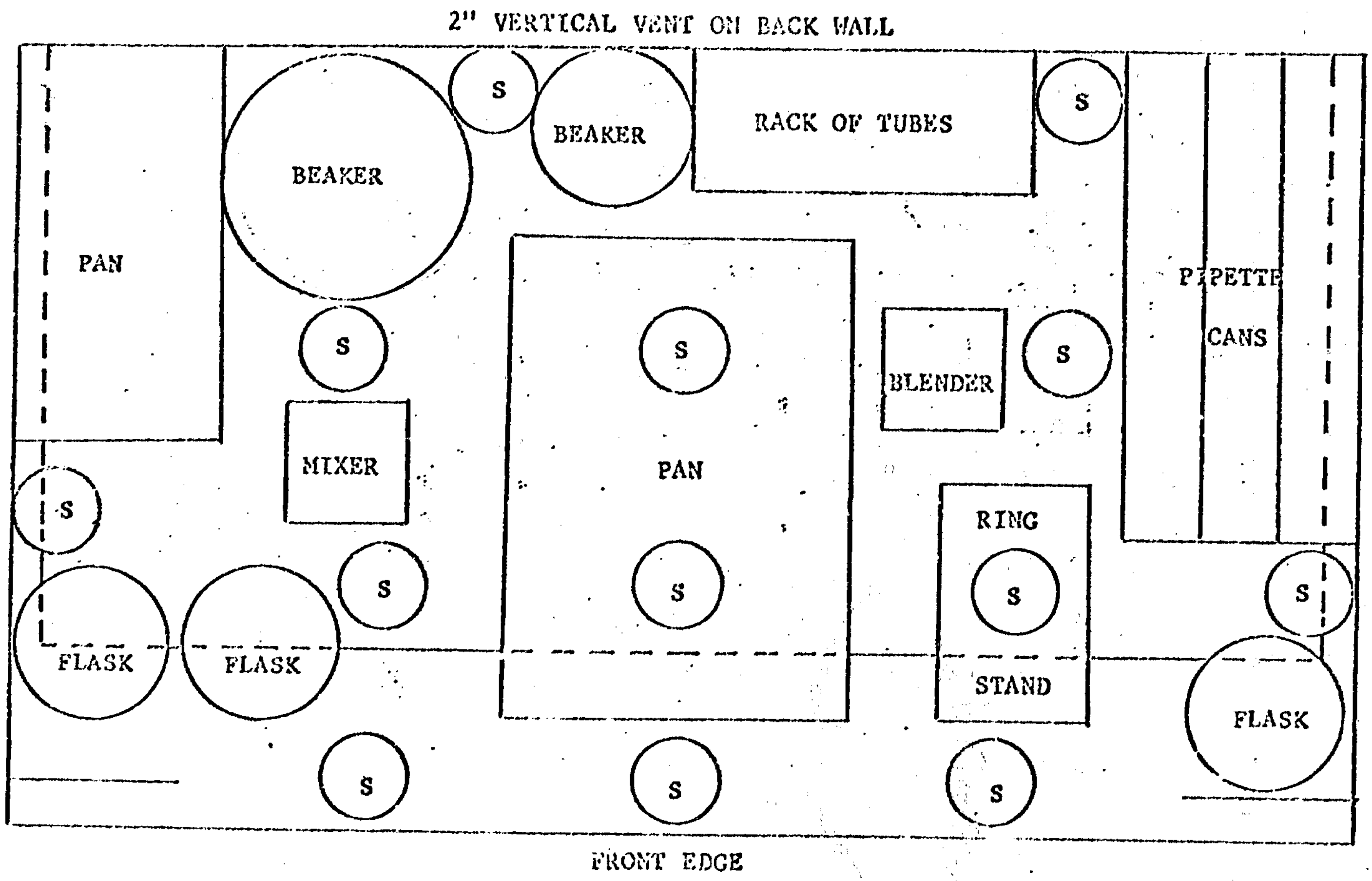


FIGURE 8A

Location of laboratory items obstructing exhaust vents in BioQuest cabinet



KEY: S = SETTLING PLATE

FIGURE 9A

Sample location and plate counts for experiment 34

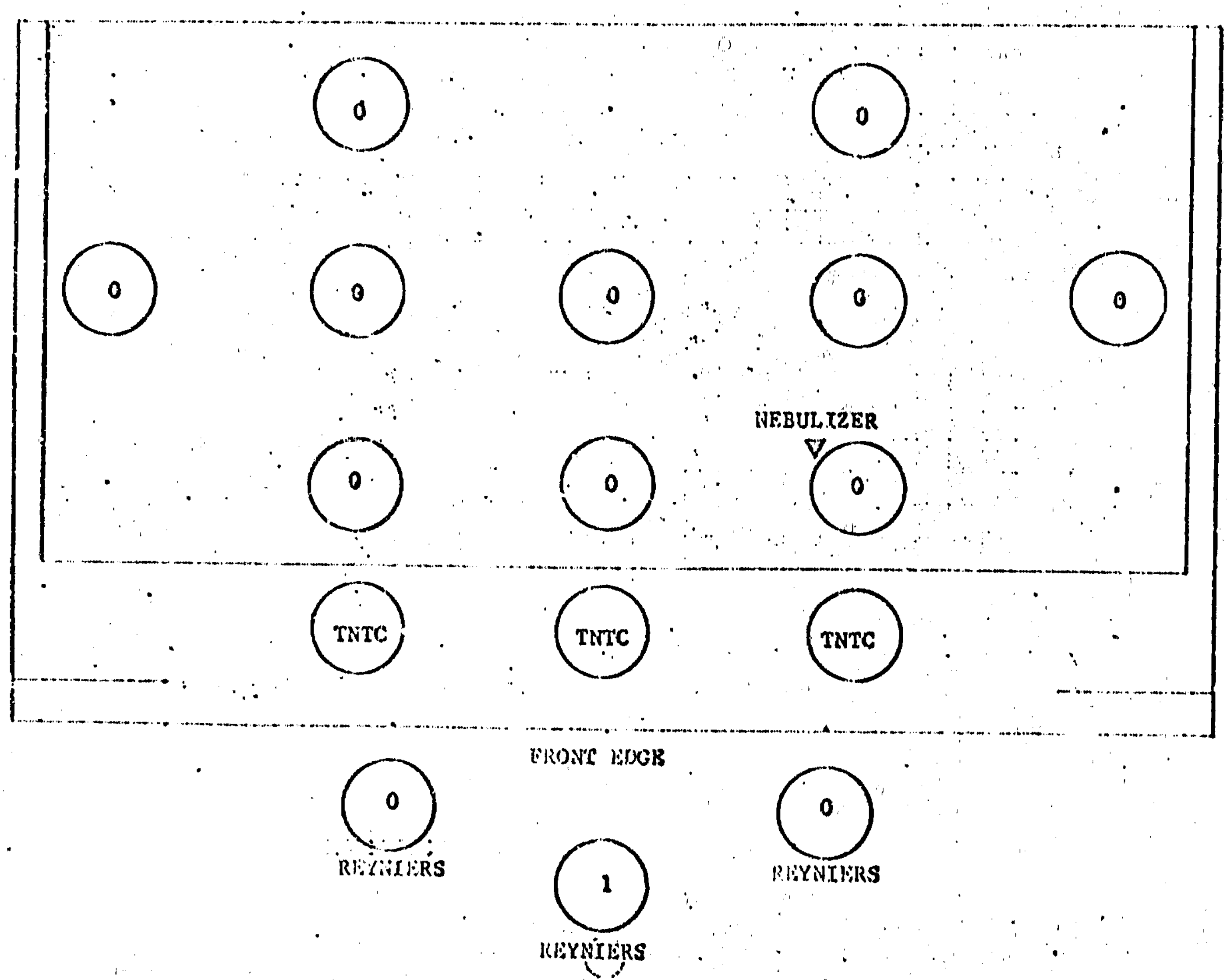


FIGURE 10A

Sample location and plate counts for experiment 34

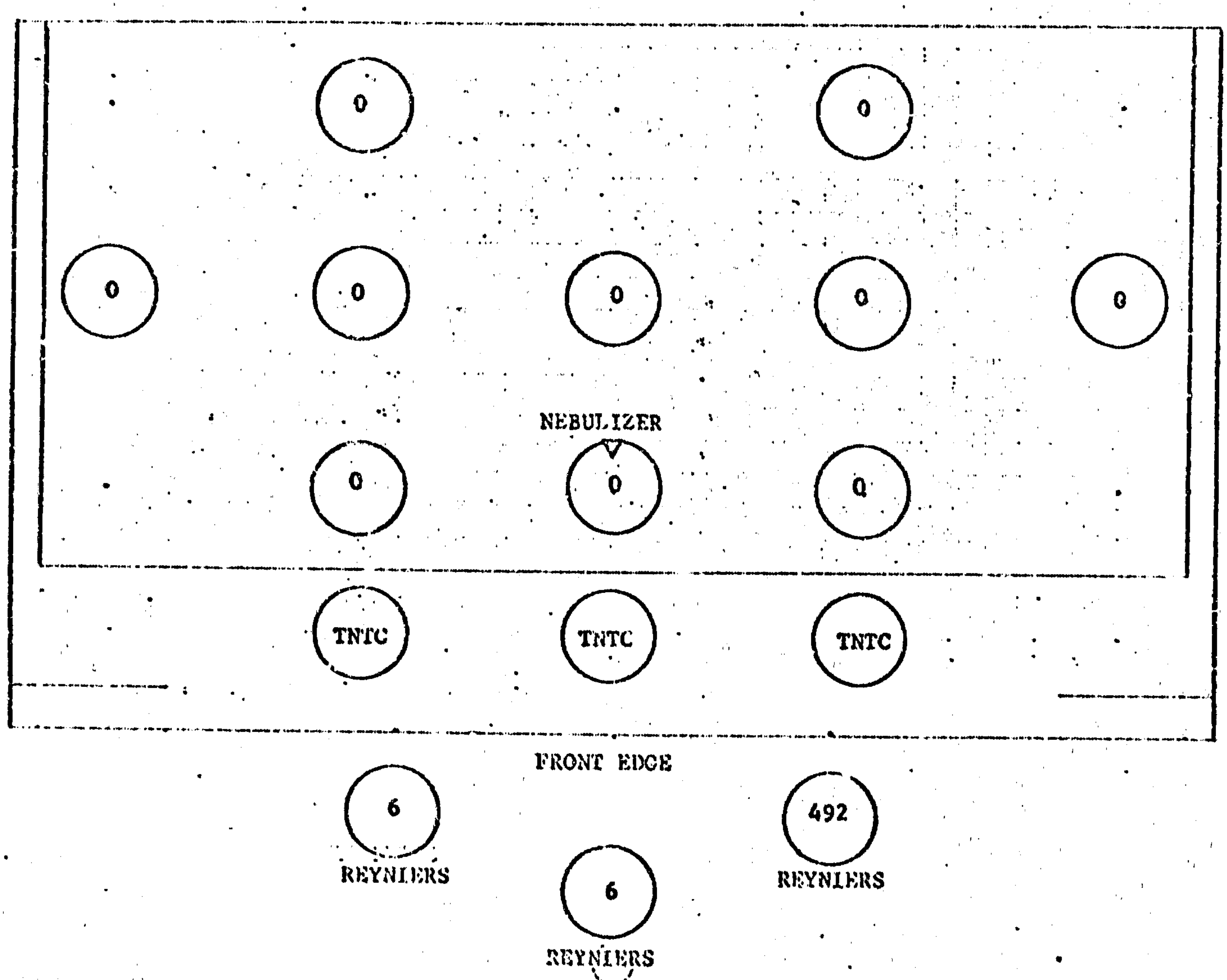


FIGURE 11A

Sample location and plate counts for experiment 34

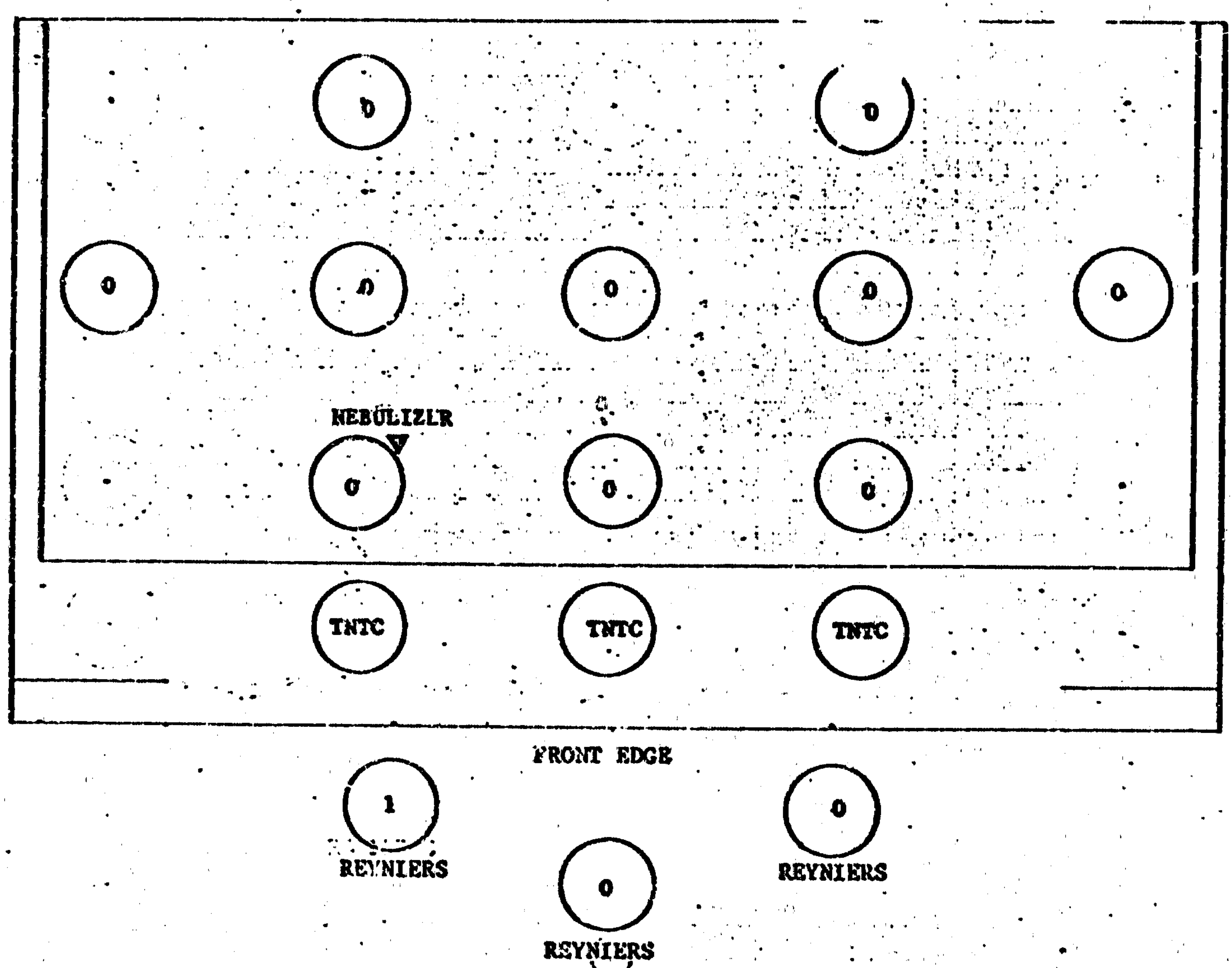


FIGURE 12A

Sample location and plate counts for experiment 35

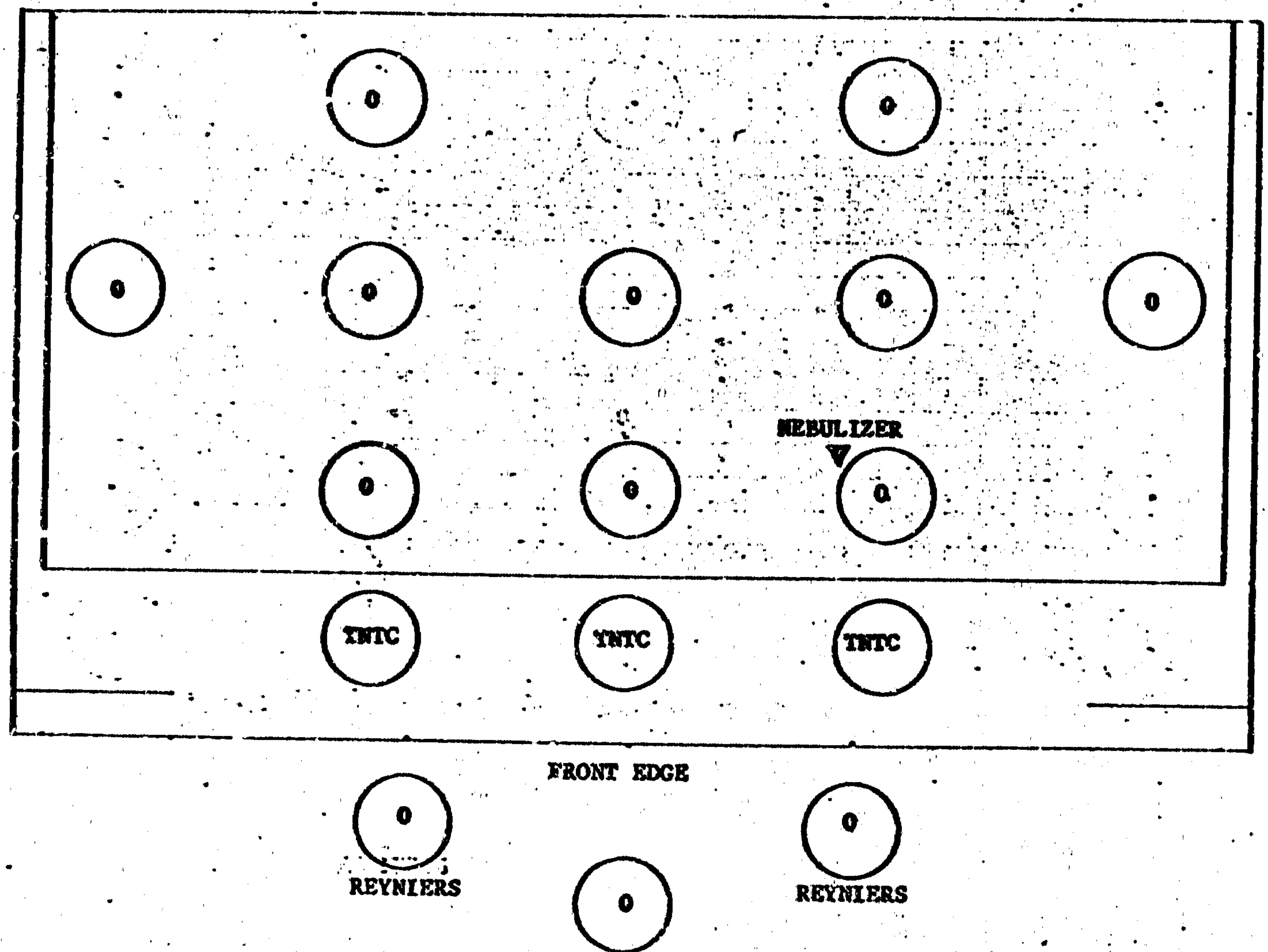


FIGURE 13A

Sample location and plate counts for experiment 35

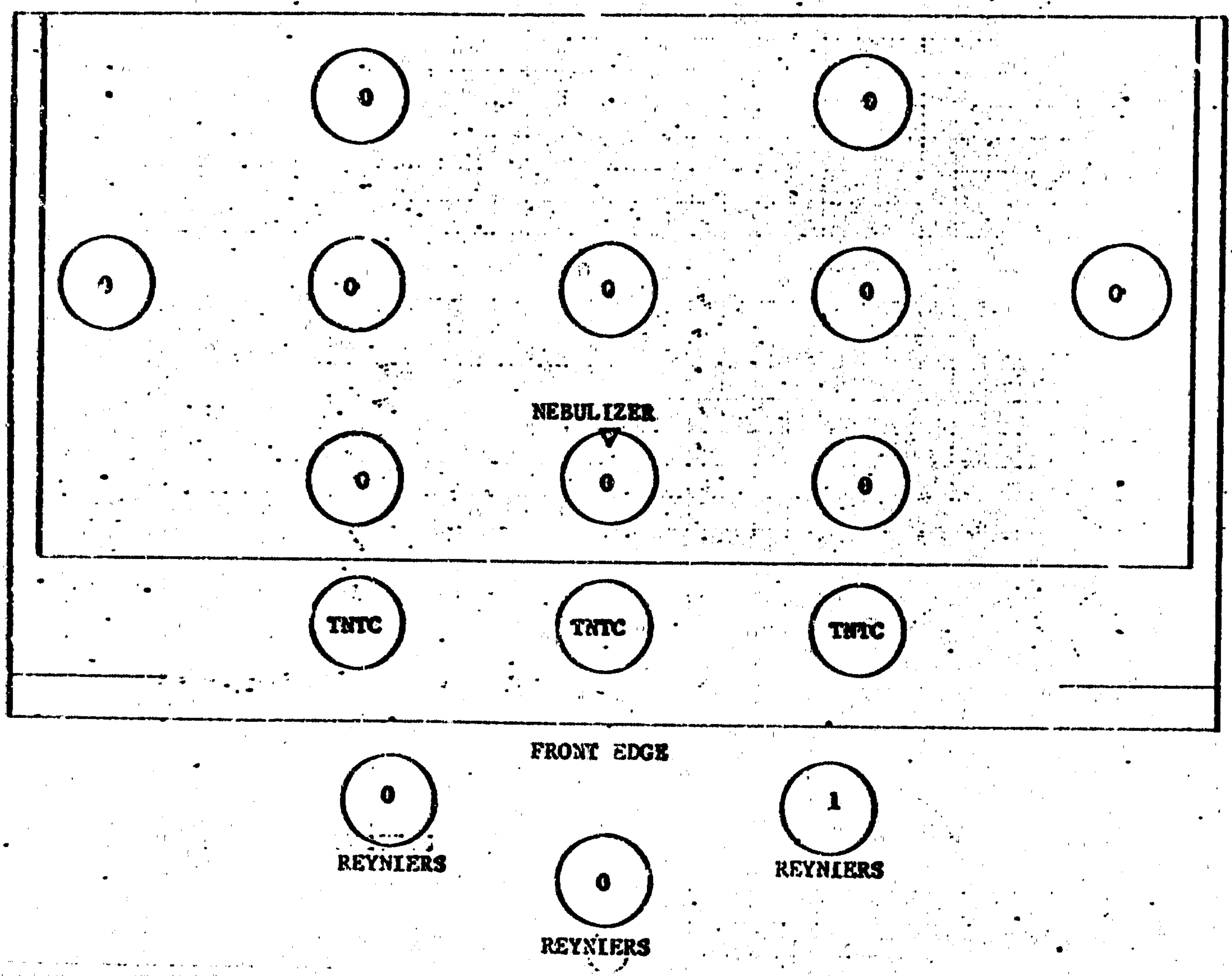


FIGURE 14A

Sample location and plate counts for experiment 35

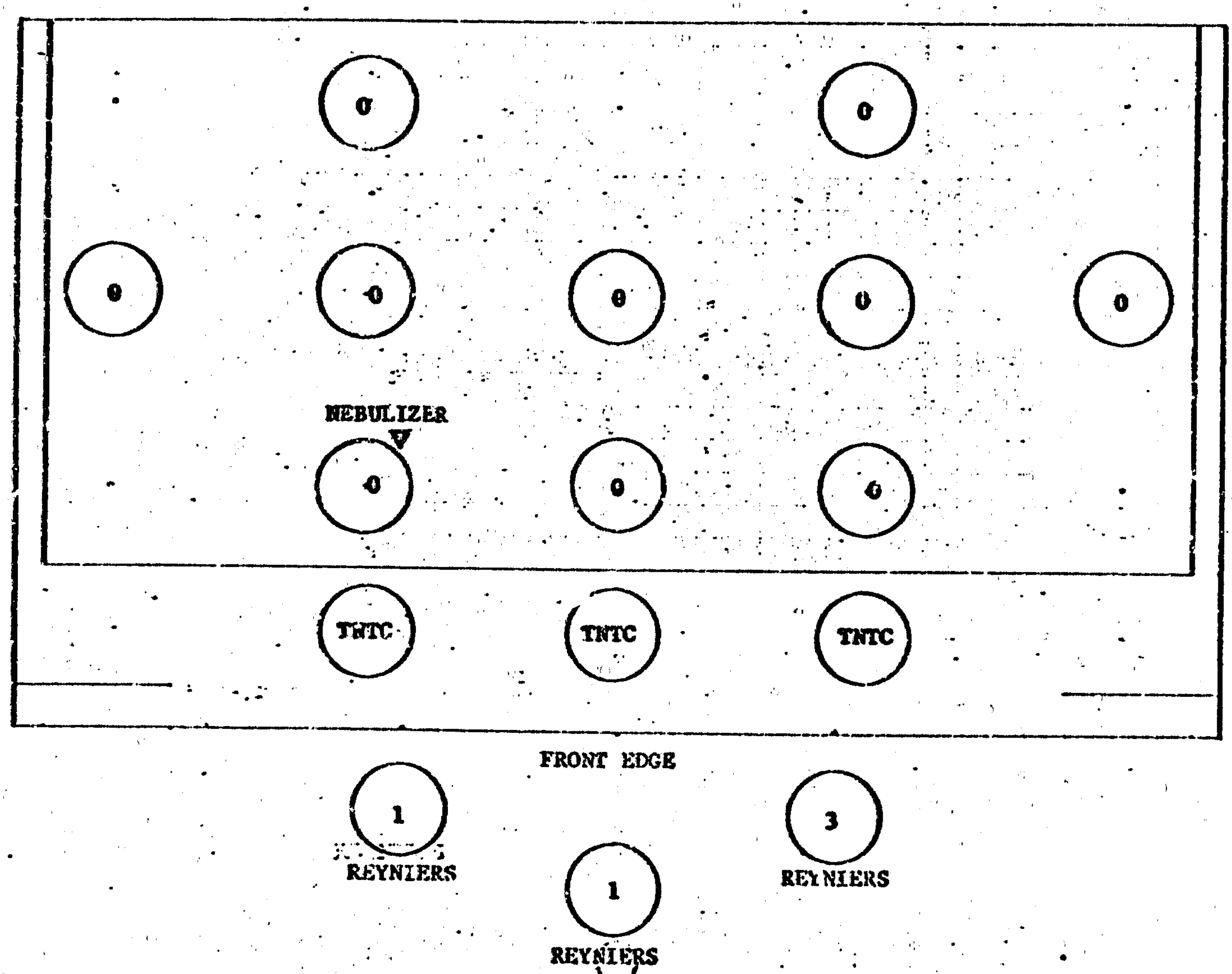


FIGURE 15A

Sample location and plate counts for experiment 36