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EFFECT OF RADIOACTIVITY ON THE BIOCHEMICAL OXIDATION OF DOMESTIC SEWAGE

Final Report

By
William E. Dobbins
Gail P. Edwards
Werner N. Grune
Richard Ehrenreich—(11)

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New York University

Technical Information Service, Oak Ridge, Tennessee

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Waste Disposal

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ABSTRACT

This study has been devoted to the effect of radioactive phosphorus, P^{32}, and radioactive iodine, I^{131}, on the course of the biochemical oxidation of fresh domestic sewage. The results indicate that P^{32} exerts no measurable effect with initial activity levels of 0.1 and 1.0 millicuries per liter but affects a very small reduction in the rate of oxygen utilization at the 10.0 millicurie per liter level. The presence of iodine, I^{131}, with initial activities of from 0.01 to 10.0 millicuries per liter, appears to produce a decrease in the rate of oxygen utilization which results in a reduction in the total oxygen demand of about ten per cent by the seventh day.

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I. INTRODUCTION

A. Object of the Research

The object of this research was to study the effect of radioactive phosphorus, P^{32}, and radioactive iodine, I^{131}, on the biological oxidation of domestic sewage, as part of a broader program designed to determine the effects of radioactive materials on sewerage systems, sewage treatment plants and bodies of water receiving sewage effluents. The biochemical oxidation reaction was chosen for the initial study because of its fundamental importance in sewage treatment processes and in the process of self purification in streams. The particular isotopes used in the study were chosen because of their relatively wide distribution and because they provided varying conditions of exposure to the sewage microorganisms. Radiophosphorus, P^{32}, a pure beta emitter, participates in the metabolism of the organisms responsible for the oxidation of the organic matter in sewage, whereas, radioiodine, I^{131}, a beta and gamma emitter is regarded as not being directly involved in the metabolism of these organisms.

B. Nature of the Biochemical Oxidation of the Organic Matter in Sewage

In the presence of excess oxygen, the decomposition of organic matter proceeds aerobically, resulting in stable and unobjectionable end products. The amount of oxygen required for the stabilization of the organic matter in sewage is usually measured by the standard BOD (biochemical oxygen demand) test[1]. The test is made by diluting the sewage with oxygen saturated water containing certain nutritive minerals

NOTE: Progress Reports previously issued under this contract: NYU-1, NYU-2, NYOO-1500, NYOO-1501, NYOO-1516, NYO-1510 and by observing the amount of oxygen depleted after various time intervals. It has been found, as a result of many such tests, that the utilization of the oxygen takes place in two stages, the first stage resulting mostly from the breakdown of carbonaceous material and the second stage from the oxidation of the nitrogeneous matter. Under ordinary conditions the second stage begins to exert its effect after the seventh to fifteenth day, whereas the complete stabilization requires about one hundred days or more. The designation of the first stage of oxidation as the carbonaceous stage and the second as the nitrogenous stage is an oversimplification, because the production of a small amount of nitrites and nitrates during the first stage shows that some of the more easily oxidized nitrogenous materials are being attacked. There is also some oxidation of the more resistant carbonaceous materials during the second stage. However, it is convenient to think of the process as taking place in two distinct stages, because the assumption allows the fitting of two separate curves which are a fairly accurate representation of the observed data.

C. Mathematical Formulation of the BOD Reaction

As a result of a great many observations of the BOD reaction it has been found that each stage of the reaction can be represented as a unimolecular, or first order reaction, in which the instantaneous rate at which the oxygen is being used is proportional to the remaining amount of oxidizable material. The first stage is usually represented by the equation

$$y = L\ (1-10^{-kt}), \qquad (1)$$

in which y = the amount of O_2 utilized in time, t,

L = the total amount of oxidizable material initially present (total first stage BOD),

k = the reaction velocity constant.

This equation usually provides a good fit to the data observed during the first stage of the oxidation of fresh domestic sewage. It properly assumes that y = zero at time t = zero is a valid point to be used in the curve fitting. However, occasionally it is found that there is either a high initial oxygen demand or an initial retardation in the process which makes it difficult to obtain a good fit to the data by use of a curve which goes through the origin. It has been suggested by Thomas[2,3], that a better fit to such data may be obtained by use of the equation

$$y = L\,(1 - 10^{-k\,(t - t_0)}), \qquad (2)$$

in which t_0 has been called the "lag period". In fitting a curve of this type to the data, the point y = zero at t = zero is not used as a valid point. A positive value for the lag period can be interpreted as indicating that the oxygen utilization does not immediately proceed at the rate which is ultimately reached. Many reasons, such as the presence of toxic agents or the initial lack of the proper organisms, might be given for this behavior. A negative value for t_0 has no physical meaning as such but can be interpreted as an indication of a condition in which there is an initial oxygen demand which is satisfied almost instantaneously.

The second stage of the reaction can be also represented by equation (2), as has been shown by Thomas[2]. In this formulation the terms in the equation are defined as before except that they refer to the second stage. Figures 1 and 2 illustrate the types of curves which are obtained from the various methods of formulation. In these figures the solid lines indicate the actual course which would be followed by the data; the solid lines with the dashed extensions indicate the fitted curves which would be obtained by the various mathematical equations. It is evident that the values of the first stage L and the first and second stage t_0 are not real physical values but must be viewed as being parameters of the curves which provide the best overall fit to the data.

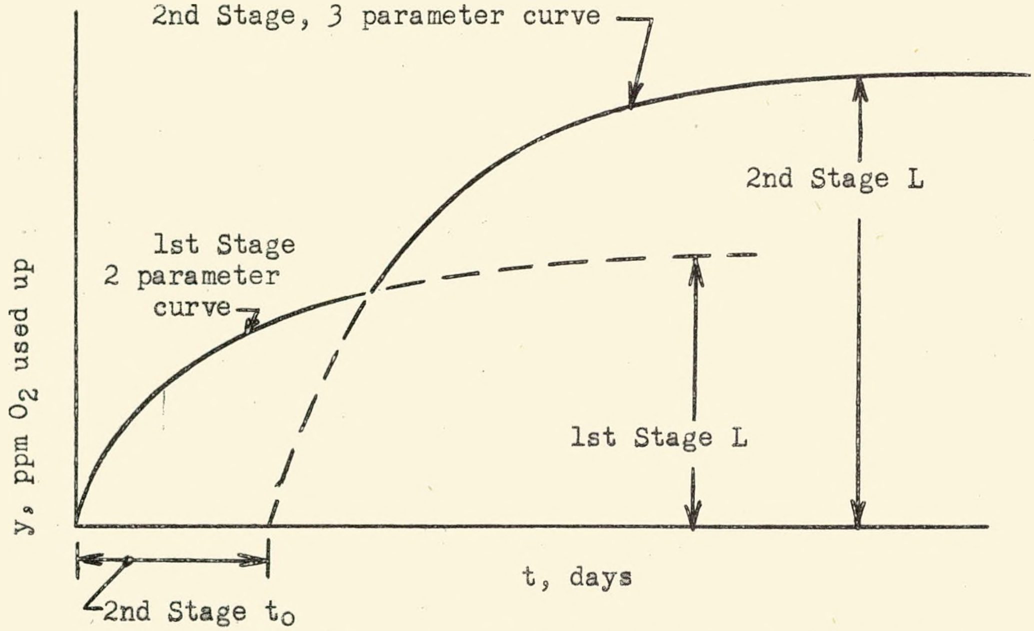

Figure 1 BOD Reaction with no Initial Lag

The effect of temperature on the BOD reaction has been widely studied and it has been found that an increase in temperature[4] increases the values of k and L. In the standard test the samples are incubated at a constant temperature of 20°C.

D. Methods of Evaluating the BOD Parameters from Observed Data

The curve representing the first stage BOD reaction in which no lag is taken into account, equation (1), can be defined by three points. Since the origin, $y = 0$ at $t = 0$, is taken as one point on the curve, two additional observations are theoretically necessary. It is common practice in the routine operation of sewage treatment plants to measure the 5 day, 20°C BOD for use as an index of the strength of the raw and treated sewages. This measurement is not sufficient to define completely the course of first stage. For the reactions which involve a lag period, equation (2), four points are required to define the curve and since the origin is not used as a point on the curve at least four observations are required.

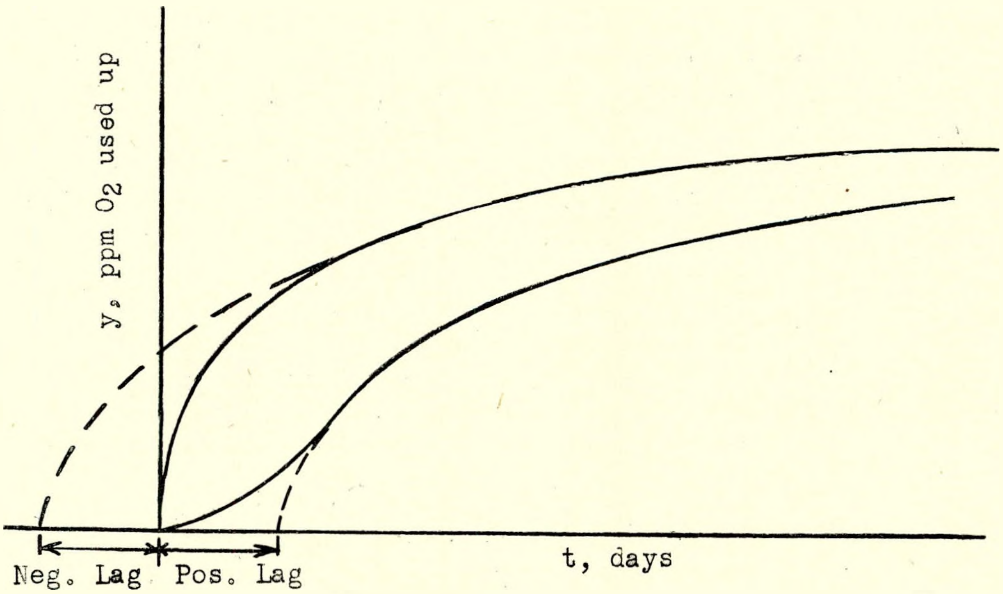

Figure 2 First Stage BOD Reactions Exhibiting Initial Lag Periods

In most cases, the second stage is of less practical interest and so no attempt is made to evaluate it.

The accuracy obtained in computing values of the parameters from the minimum required number of points would obviously be quite poor. Thomas[2] has shown how the probable errors in k and L decrease as the number of experimental points increases. Furthermore, if a two parameter curve is fitted to most BOD data, the values obtained for k and L will usually vary with the number of experimental points used in their computation. After a certain number of points have been used the values will be reasonably constant. This shows that the parameters are not necessarily true constants because of the initial lag or the apparent initial demand. It was this defect in the two parameter formulation which led to the development of the three parameter method. It is shown in the appendix to this report that the values of k decreased and the values of L increased as more daily points were used in the computations. After the sixth day the values remained reasonably constant. This was evidence that the initial rate of oxygen uptake was somewhat higher than the fairly constant rate which finally prevailed. Calculations by the "Three Moment" method indicate that the values of t_0 were slightly negative on the average, thus confirming the higher than average initial demand.

Various methods have been proposed for calculating the parameters of the curve of best fit to a given set of BOD data. It is commonly considered that the curve of best fit is the one for which the sum of the squares of the deviations of the points from the curve is a minimum. The application of the method of least squares to the fitting of BOD data was first presented by Reed and Theriault[5]. Unfortunately this method is quite laborious since it involves the use of a trial value of k which must closely approximate the value of k ultimately obtained, if repetition of a long series of computations is to be avoided. Recently Moore et al.[3] have published the "Method of Moments" for fitting a unimolecular equation to BOD data. They have shown that the values of k and L obtained by this method are very close to those obtained by the method of least squares when the computations are based on a series of seven points taken a day apart. A "Two Moment Method" is used for fitting a two parameter curve and the "Three Moment Method" for fitting a three parameter curve to data exhibiting a lag.

It is important to understand that when a three parameter curve is fitted to a set of first stage BOD data, i.e. when the origin is not taken as a valid experimental point, the values of k and L obtained along with the lag, t_0, may vary considerably from the values of k and L obtained from a two parameter fit to the same data. This is illustrated by figure 3 which shows the two different curves fitted by the moment methods to the data obtained from control run No. 16 which was made in this research. It should be noted that the values of k and L for the three parameter curve differ markedly from those for the two parameter curve although each curve appears to be a reasonable representation of the data in the range of the first seven days. If the curves were extended the divergence would become more apparent because of the considerable difference between the values of L.

E. Specific Aspects of the BOD Reaction Studied in this Research

Since the first stage of the reaction is of much greater practical interest than the second stage the work has been devoted principally to a study of the effect of various concentrations of radiophosphorus, P^{32}, and radioiodine, I^{131}, on the course of the first stage reaction. A few runs

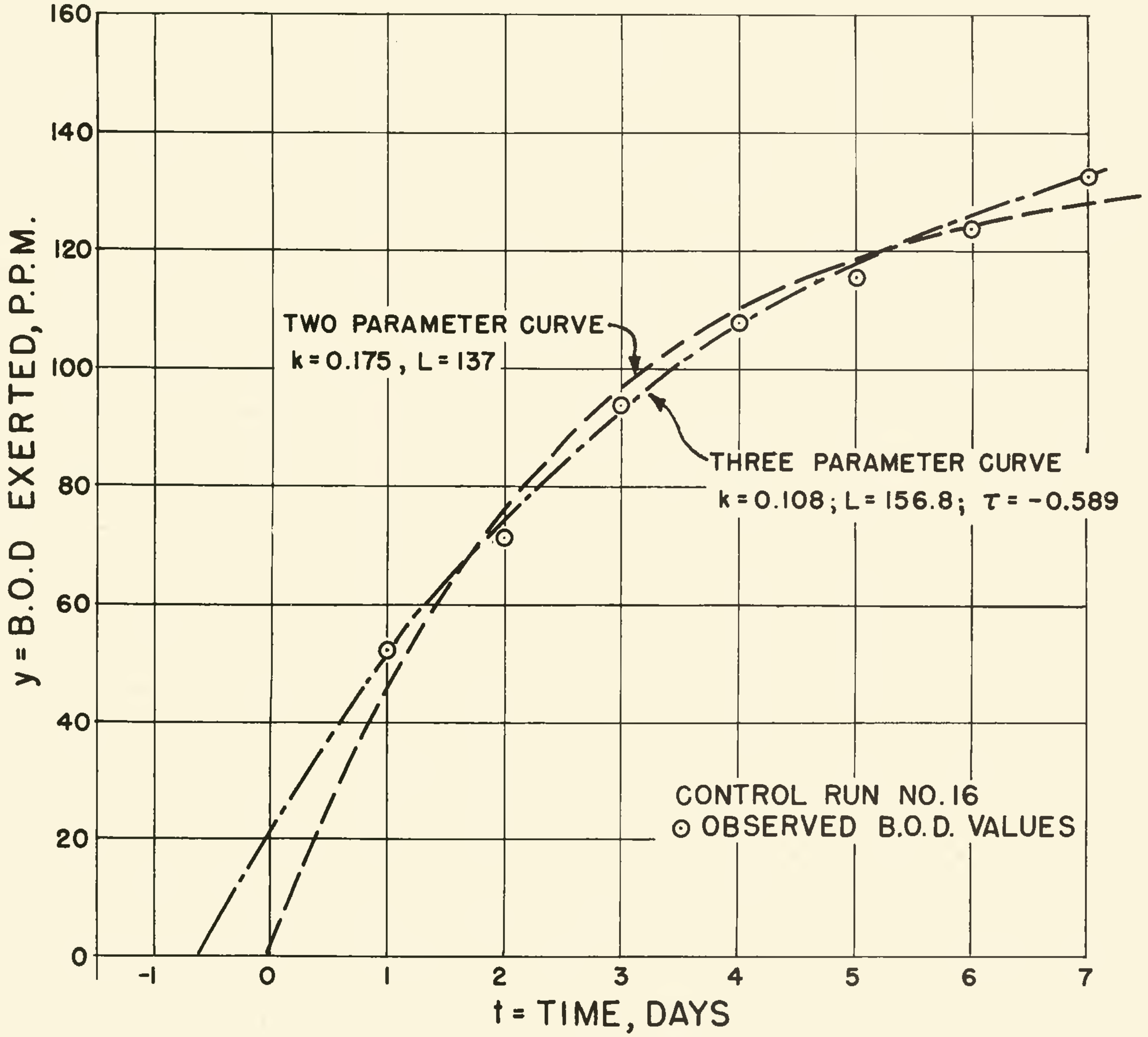

FIG. 3 Two Parameter and Three Parameter Curves Fitted to the Same B.O.D. Data

were continued well into the second stage but the data are so scant that few conclusions can be drawn from them. The study was made by making parallel runs using sewage alone and sewage dosed with various concentrations of the radioactive isotopes. The oxygen uptake was measured each day for seven days so that values of the first stage parameters could be computed from a series of seven points in each case.

As the work progressed the data were analyzed by both the "Two Moment Method" and the "Three Moment Method". It was at first believed that the three parameter fit might prove to be the more suitable for the purposes of comparison since it is more sensitive to varations in the data. However, because of the extreme variation in the values of k and L obtained by the "Three Moment Method" and because the values differ markedly from those widely reported by other investigators, the statistical comparisons reported herein were based upon the values obtained by the commonly used two parameter method. The statistical studies of the "Three Moment" parameters did not alter any of the conclusions.

Further supporting evidence of any effects of the radioactivity on the reaction included measurements of production of nitrites and nitrates and also some limited studies of relative bacterial populations.

The concentrations of radioactive materials were chosen so as to be well above the maximum levels likely to be encountered in practice. The studies were made with initial activities ranging from 0.01 to 10.0 millicuries per liter of P^{32} or I^{131}. These activity levels compare with 5 X 10^{-4} millicuries per liter of I^{131} and 10^{-4} millicuries per liter of P^{32} which were set by the Isotopes Division of the Atomic Energy Commission on September 20, 1948 as maximum permissible concentrations which could be discharged by an institution into a public sewer.[6]

II. LABORATORY PROCEDURE

A. General

The experimental work was carried on in two separate laboratories. All work with radioactive materials was performed in the "hot" laboratory previously described[7] in Progress Report 5 and all work with non-radioactive materials was done in the "cold" laboratory. The general procedures in each laboratory were identical.

B. Source of Sewage

The sewage used during this investigation was collected from a manhole located near the laboratory on West Burnside Avenue, Bronx, New York. The sewage was a relatively weak domestic one, typical of that collected from the western Bronx and upper Manhattan. The sewage was filtered through non-absorbent cotton to remove large suspended solids prior to its addition to dilution water for the BOD tests.

Although the use of synthetic sewage was considered, it was not used because the primary objective of the study was to determine the effect of radioactive substances on raw domestic sewage. Difficulties in obtaining a representative bacterial population by seeding and in interpreting and comparing the data also favored the use of actual sewage.

C. Method of Chemical Analysis

All analyses were made in accordance with procedures outlined in the ninth edition of "Standard Methods for the Examination of Water and Sewage"[1]. The Winkler Method with the azide modification was used throughout for the determination of dissolved oxygen. The determinations of ammonia, nitrite and nitrate nitrogen were made colorimetrically with a Beckman Spectrophometer, model D. U.

The BOD bottles had a capacity of 8 ounces and were provided with a large water seal. Evaporation of water from the seal was retarded by placing an inverted glass cap shaped like the end of a test tube over the stopper.

D. Radioactive Materials

(a) Phosphorus - Radiophosphorus (P^{32}) was received from Oak Ridge in the form of ortho-phosphoric acid with 7,000 to 10,000 times as much carrier phosphate added to reduce adsorption losses. Orthophosphates are readily adsorbed on the surfaces of glass containers as well as being utilized in the metabolic processes of numerous micro-organisms. The half life of radiophosphorus is 14.13 days[8]. It emits a pure beta ray of 1.74 M.E.V. and decays to stable sulfur (S^{32}).

(b) Iodine - Radioiodine(I^{131})as received from Oak Ridge was the carrier free elemental iodine, but the solution contained 1.0 gram per liter of sodium hydroxide (NaOH) to retard volatilization of the iodine and 0.1 gram per liter of sodium bisulfite ($NaHSO_3$) as an oxidation inhibitor. The half life of radioiodine (I^{131}) is 8.0 days[8]. It emits both beta and gamma radiation and decays according to the following scheme: approximately 85% emits a beta ray at 0.60 M.E.V. and three discrete gamma rays at 0.08, 0.28 and 0.37 M.E.V; approximately 15% emits a 0.32 M.E.V. beta and a 0.64 M.E.V. gamma ray; less than 1% decays to Xenon^{131} (half life of 12 days) and emits a gamma ray of 0.16 M.E.V., decaying to stable Xenon.

E. Procedure for BOD Determinations

A flow diagram of the procedure for setting up the dilution waters is shown in Figure 4. Five 5 gallon carboys of distilled water were aged for one week and aerated for another week. The water was transferred to a 30 gallon crock and stored for an additional week to allow the dissolved oxygen content to come to equilibrium with the atmosphere.

The salts needed to make standard dilution water were added to the crock on the morning of each run. After thorough mixing, three portions of water were withdrawn into carboys for use as blanks in the hot laboratory and one additional portion for the non-radioactive blanks (Steps 1 and 2).

In the hot laboratory, the three portions of water used for the hot blanks were dosed with radioactive phosphorus or iodine to the three levels of activity to be used in the sewage samples (Step 3). These were generally 0.1, 1.0 and 10 millicuries per liter, although a few runs were made to include levels of 0.01 and 0.001. The exact amount of radioisotope required to bring the dilution water to the desired levels of radioactivity was pipetted by remote control from the "high

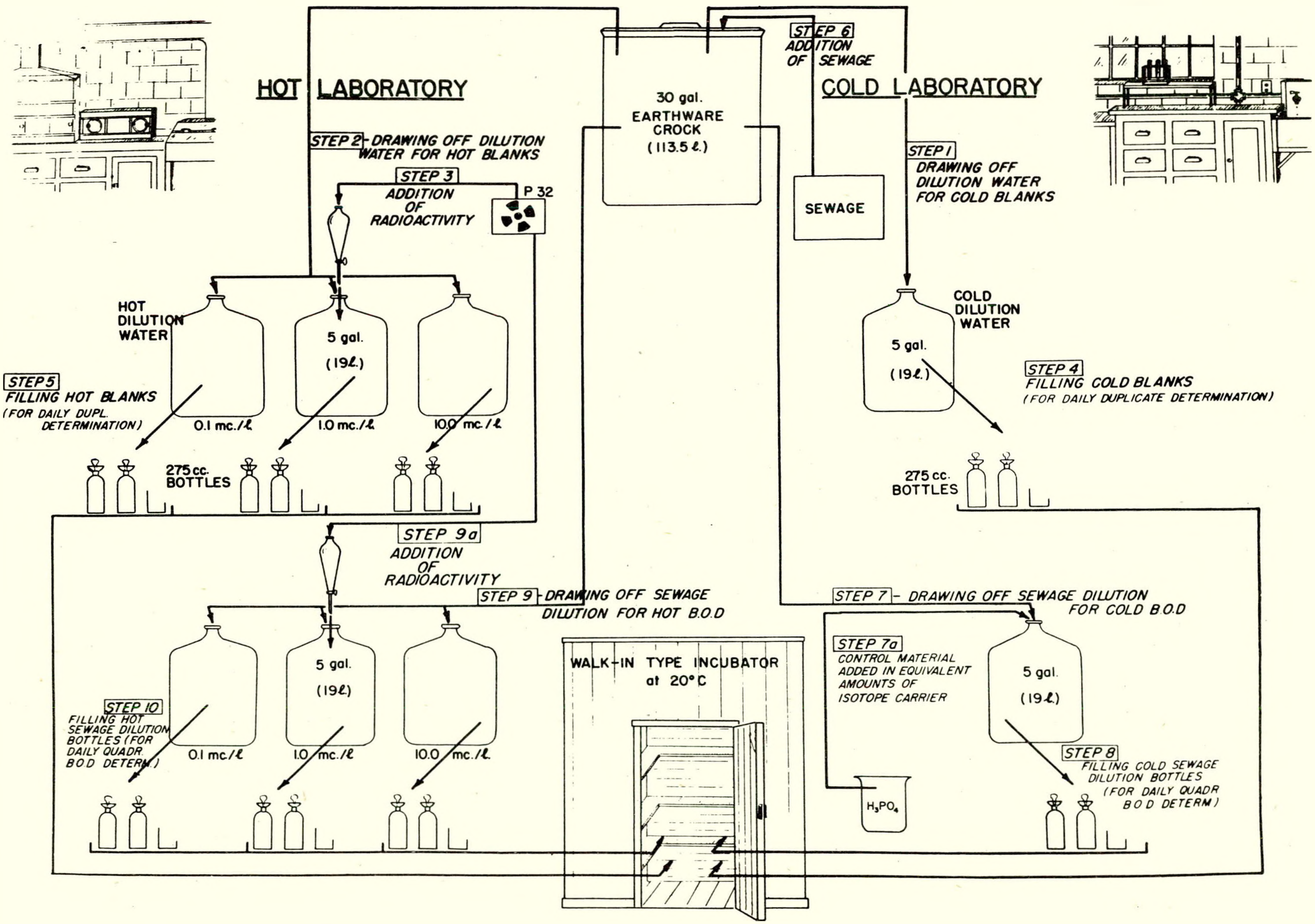

Fig. 4--Flow diagram of experimental procedure.

Fig. 5--High intensity hood.

Fig. 6--Lead lined container for Erlenmeyer Flask.

Fig. 7--BOD bottle filling unit.

Fig. 8--Shielded separatory funnel.

intensity" hood to an erlenmeyer flask containing some dilution water (Figure 5). This was carried in a lead lined container to the bench where the BOD bottle filling unit was located (Figures 6 and 7). The contents of the flask were poured into a shielded separatory funnel, raised by a pulley system (Figure 8) and then allowed to flow into the carboy containing the dilution water (Step 3). The flask and funnel were rinsed with dilution water to remove residual material and the rinsings were poured into the carboy. After mixing, sufficient water was transferred by siphon to the BOD bottles to provide for duplicate blanks for each day (Step 5).

An amount of normal orthophosphoric acid, or of stable iodine, equivalent to the amount of carrier in the radioactive material was then added to the cold dilution water. The exact amount added was equal to the amount of carrier materials in the hot dilution water which had been dosed to the highest level of activity. In the case of the phosphates, this amounted to about 0.02 ppm of H_3PO_4, a small amount when compared with the phosphate buffer in the dilution water. In the case of the iodine it amounted to about 0.002 ppm. After mixing, the cold blanks were siphoned into BOD bottles for daily duplicate determinations (Step 4).

Sewage was added to the remainder of the water in the 30 gallon crock to make a 4% sewage dilution (Step 6). After mixing, the diluted sewage was siphoned into four carboys (Steps 7 and 9). One of these remained in the cold laboratory for the cold BOD determinations (Step 7). The equivalent carrier material was added, as in the case of the cold dilution water (Step 7a), and after mixing, the cold sewage was siphoned into the BOD bottles so as to provide for daily quadruplicate BOD determinations (Step 8).

The other three carboys were moved to the hot laboratory, the desired amount of isotope added, (Step 9a), and the BOD bottles were filled by siphon to permit quadruplicate determinations of BOD for each day (Step 10).

Immediately after the bottles were stoppered and capped, they were incubated at 20°±1°C in a walk-in type of incubator. Both hot and cold bottles were stored in the same incubator, but were separated by plexiglass or lead shielding to prevent irradiation of the cold samples.

To determine the initial or zero day dissolved oxygen content of the dilution water, two BOD bottles were filled with the initial portion withdrawn from the carboy and two with the final portion. The same procedure was followed for the sewage dilutions.

For the first stage studies, dissolved oxygen determinations were made on each of the first 7 days. For a limited number of runs, determinations were carried on into the second stage.

F. Technique for the Dissolved Oxygen Determination

Four BOD bottles and two dilution water blanks for the cold sewage and for each of the three levels of radioactivity were taken from the incubator each day for dissolved oxygen determinations. The cold samples were handled in the conventional manner in the cold laboratory. In the hot laboratory reagents were added by means of the three Caulfield pipettors. The bottles were placed in the Berkeley-type dry box and thoroughly shaken to allow the reactions to take place. All bottle handling was done through the permanently fastened gauntlet-type gloves (Figure 6). The bottles were then moved through a sliding door into the shielded titration unit, where the samples were titrated with standard sodium thiosulfate. During the titration operation the bottles were handled with rubber gloves.

After the analyses were completed, all radioactive liquids were dumped inside the titration unit which drained to the sewer. A large factor of dilution was maintained by a continuous flow of water whenever radioactive work was carried on. Each bottle was immediately flushed with tap water inside the titration unit by means of a foot-pedal controlled spigot. After this initial rinse, the BOD bottles were inverted over a water-jet bottle washer inside a stainless steel double sink (Figure7) and allowed to remain for twenty to thirty minutes.

G. Nitrogen Determinations

A separate BOD bottle from each of the activity levels was taken out of the incubator each day and set aside for pH, ammonia, nitrite and nitrate determinations. A Coleman pH electrometer was used to determine the pH of the samples. All of the nitrogen determinations were carried out colorimetrically on a Beckman Quartz Spectrophotometer, model D. U., using 100 mm. cells. Large cells were found necessary for detecting the small amounts of nitrogen compunds formed. Varying dilutions of the sewage samples were used as nitrification progressed.

H. Bacteriological Examinations

The bacteriological examination consisted of plate counts on tryptone glucose agar after incubation for 48 hours at 20°C. The samples as diluted for the BOD test were further diluted when necessary for the plate count. The data are expressed as thousand of bacteria per milliliter of sample as diluted for the BOD test. In order to convert to a raw sewage basis, it would be necessary to multiply each value by the dilution factor which is generally 25. In the phosphorus study, four dilutions with one plate each were used for the control and each of the three levels of radioactivity. In the first twelve iodine experiments, three dilutions with one plate of each dilution were made. Thereafter, only two dilutions but three plates of each dilution were used.

J. Decontamination of Glassware

When radiophosphorus was under study, glassware was decontaminated with disodium acid phosphate, Na_2HPO_4. After the rinse with tap water, the BOD bottles were filled with a saturated solution of Na_2HPO_4 and allowed to stand one or two days. The stoppers were also soaked in Na_2HPO_4. This method, which depends upon the exchange of stable phosphorus (P^{31}) for radiophosphorus (P^{32}) proved to be very efficient. The activity of the bottles after use, which was as much as 20 milliroentgens per hour at a distance of 0.5 inch, was reduced to 0.2-0.3 milliroentgens per hour after a 24 to 48 hour soak in the disodium acid phosphate solution.

With radioiodine, the decontamination problem was less serious as the thorough tap water rinse removed practically all radioactivity. Residual activity was removed by soaking the glassware in 0.1N oxalic acid, $H_2C_2O_4$.

K. Counting Procedure

During the progress of the research the relative activity levels of various radioactive solutions were measured. The principal purpose was to determine whether or not the radioactive materials were being removed from the sewage dilutions by adsorption and sedimentation. To accomplish this daily determinations for seven days were made of the activities of sewage dilutions and compared with the activity of a distilled water dilution of the isotope solution received from Oak Ridge. From the data thus obtained the values of the decay constant, λ, in the equation, $A = Ao \times 10^{-\lambda t}$, were computed by the method of least squares.

In this equation A is the activity at the end of t days, and Ao is the initial activity. The portions taken for counting were drawn from bottles which were allowed to stand undisturbed for the period of seven days. If any appreciable removal of the radioactive elements had occured this fact would have been brought out by an apparent increase in the value of the decay constant, λ. The computed values of λ, which are tabulated in the Appendix, showed that on the average there could not have been much separation of the radioactive isotopes from the liquid.

The liquids to be counted were first diluted so as to bring the zero day count down to about 2000 counts per minute. The quantity of liquid used for counting was two milliliters in all cases. Duplicate samples were pipetted from the bottles into pyrex ashing dishes approximately 0.64 cm. high and 2.2 cm. in diameters. Each sample was placed on an aluminum tray, inserted into a lead shield and counted by an open end, mica window-type Geiger-Muller tube and scaler. The duplicate samples were counted in separately operated units.

III. EXPERIMENTAL RESULTS

The experimental results obtained with P^{32} are given in Tables 1 through 13 and on Figure 9 on the following pages. The results obtained with I^{131} are given in Tables 14 through 29 and on Figure 10.

IV. ANALYSIS OF RESULTS

A. General

Considerable variation is observed in the y values and in the values obtained for the BOD reaction parameters. As was to be expected, the largest variations occured between the different runs because of the great variability in the character of the raw sewage. Much less variation is to be noted for the values obtained at the different levels of radioactivity with the same sewage. It is not possible to determine by casual study of the data how much of the variation is due to experimental errors and how much may have been caused by the radioactivity.

Sources of possible error due to experimental technique were (1) lack of perfect uniformity in the amount of sewage and seeding organisms in all the bottles which were filled for incubation at the start of each run (2) slight variations in the temperature of incubation and (3) errors in the dissolved oxygen determinations. Another source of error in arriving at the values of the parameters

TABLE 1

y^* VALUES WITH P^{32}

0.1 mc/liter

DAY

RUN	1	2	3	4	5	6	7
17	37.9	59.1	82.3	92.5	104.3	111.3	114.8
18	28.7	49.7	73.3	82.3	87.3	92.1	94.8
19	45.6	69.3	90.6	106.8	118.4	122.9	136.4
20	16.4	23.2	37.9	43.9	46.3	46.7	45.1
21	40.5	64.5	85.2	105.3	109.0	116.6	118.1
22	50.1	73.9	106.1	120.0	129.2	139.0	144.3
23	61.4	83.2	101.9	122.9	139.2	140.8	149.4
24	36.7	52.7	82.2	101.7	108.8	111.8	118.8
25	35.5	47.4	69.6	79.8	88.6	92.6	97.2
26	53.5	73.0	101.0	114.8	125.3	131.8	133.2
27	41.6	57.7	65.2	83.2	97.0	107.0	114.8
28	47.2	66.9	84.6	101.4	109.4	115.5	119.7
29	43.7	67.5	85.0	98.6	107.1	115.1	117.6
30	35.6	62.7	89.5	104.0	114.5	121.5	128.3
31	51.8	75.2	99.5	110.0	122.6	127.9	133.5
32	36.4	54.5	79.1	90.7	99.4	102.7	103.0
33	69.8	113.7	133.9	147.2	166.0	176.8	181.8
34	46.2	74.6	92.2	100.9	108.2	113.4	118.2
35	51.8	82.7	98.2	112.0	108.7	112.6	118.7
36	52.4	77.4	94.0	101.5	109.3	111.1	116.6
37	45.4	69.6	83.1	96.9	97.1	95.9	102.6
38	45.3	77.1	98.6	109.7	116.3	120.8	131.4
39	37.1	62.8	66.9	86.2	97.4	104.3	107.6

Note: The values reported for y on this and on succeeding tables were calculated to the nearest tenth of a part per million for the purpose of statistical computations. For any one value, the figure to the right of the decimal point is not significant.

* in parts per million of BOD exerted

TABLE 2

y VALUES WITH P^{32}

1.0 mc/liter

RUN	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
1	29.0	39.1	42.8	45.9	49.1	55.9	59.1
2	36.4	53.0	59.1	68.2	67.4	73.4	77.2
3	29.5	68.8	77.2	86.3	90.8	94.5	95.9
4	47,3	76.0	95.0	110.8	115.8	114.6	119.3
5	14.0	23.0	22.3	27.4	26.4	29.1	35.1
6	38.0	55.8	61.0	66.0	78.5	63.8	67.5
8	40.9	54.7	85.4	97.7	100.2	103.5	100.7
9	34.2	48.0	71.5	75.5	79.2	81.7	84.2
10	29.3	43.5	64.3	72.3	81.5	84.8	86.1
12	60.7	84.2	117.0	134.2	144.2	155.2	156.6
13	42.3	57.5	82.8	95.5	107.1	112.1	113.6
14	53.5	74.8	100.3	116.6	128.1	131.4	140.5
15	40.9	65.0	84.1	100.1	108.9	112.5	115.1
16	54.0	72.3	95.3	109.1	117.4	121.1	126.6
17	37.9	58.4	81.5	92.5	100.0	106.3	110.5
18	23.3	47.1	71.1	82.6	88.3	92.8	94.9
19	45.6	70.6	95.4	110.6	125.9	133.2	140.2
20	15.5	21.8	37.7	43.9	44.3	45.7	47.4
21	41.7	63.2	90.7	99.0	109.5	113.5	117.3
22	54.1	78.2	109.8	124.8	134.4	142.4	149.0
23	64.0	82.1	94.3	120.6	130.9	145.4	150.4
24	38.9	55.2	79.8	101.1	107.3	114.3	120.3
25	35.8	48.4	73.2	83.2	87.6	95.2	108.9
26	54.4	71.7	99.1	116.1	121.1	131.1	135.4
27	42.6	59.4	68.5	84.1	97.1	111.6	113.1
28	46.4	65.1	88.6	105.0	109.6	118.1	122.1
29	44.4	68.2	87.0	99.8	112.1	117.6	120.2
30	38.1	62.7	88.2	96.5	113.3	120.3	125.9
31	50.6	72.7	96.8	110.0	120.9	129.7	134.3
32	34.4	53.9	65.3	96.6	97.1	100.9	104.4
33	53.9	85.7	103.2	113.2	123.6	129.2	142.0
34	43.6	65.7	95.7	105.0	105.0	116.3	118.6
35	52.4	86.1	98.1	115.6	112.4	118.2	122.7
36	48.4	72.4	92.5	99.8	103.1	110.1	115.4
37	44.9	69.1	83.2	93.4	94.9	98.5	103.1
38	44.1	81.9	107.1	110.0	115.0	122.6	131.0
39	37.9	59.1	74.8	89.3	96.9	106.9	111.8

TABLE 3

y VALUES WITH P^{32}

10.0 mc/liter

DAY

RUN	1	2	3	4	5	6	7
17	41.6	59.0	82.8	94.9	103.9	109.9	113.6
18	28.8	46.7	71.7	81.8	89.0	94.1	99.1
19	49.6	70.9	94.7	112.7	125.5	128.5	139.3
20	17.1	23.4	36.9	43.9	45.5	47.7	49.9
21	20.1	37.2	56.9	84.1	93.6	101.2	102.5
22	55.9	78.8	109.3	125.6	131.2	136.8	141.9
23	61.6	82.9	93.1	115.9	138.5	140.8	144.2
24	38.5	57.3	81.9	94.4	106.2	112.0	115.2
25	37.6	48.6	68.4	80.4	87.8	91.4	95.1
26	47.3	69.6	90.8	113.3	123.6	126.5	129.6
27	49.1	58.5	67.2	82.4	96.7	106.3	109.8
28	26.3	54.4	84.7	97.6	106.4	112.2	115.9
29	19.4	48.3	74.9	91.9	99.7	102.8	107.8
30	26.4	50.8	82.1	96.7	104.2	111.0	115.6
31	45.6	70.8	90.4	107.7	115.7	121.8	128.8
32	28.2	51.5	73.4	85.5	95.5	101.5	103.1
33	64.1	90.8	110.0	122.1	134.3	140.4	145.9
34	37.3	62.2	86.5	95.1	100.6	109.1	112.6
35	53.7	83.1	95.7	105.7	114.8	117.8	129.1
36	47.2	72.4	91.3	97.6	106.2	107.0	111.8
37	44.6	69.9	82.4	91.9	96.7	98.8	102.0
38	42.9	83.4	102.1	111.2	118.0	123.8	131.1
39	36.7	63.9	73.6	88.0	106.0	115.7	117.0

TABLE 4

y VALUES WITH P^{32}

CONTROL

DAY

RUN	1	2	3	4	5	6	7
1	17.7	39.0	44.0	48.3	50.2	52.7	56.6
2	33.4	49.6	60.1	69.3	73.2	78.2	76.8
3	51.1	85.8	88.2	90.3	96.0	101.7	103.5
4	43.3	60.0	77.0	102.1	108.3	112.1	118.6
5	11.5	16.3	17.6	26.1	26.4	31.6	34.4
6	25.8	42.8	46.5	55.5	59.3	64.0	65.0
8	42.1	62.4	74.4	89.4	102.4	105.6	106.9
9	36.6	50.4	71.6	80.4	92.6	97.9	98.3
10	32.1	50.6	70.1	80.9	84.9	91.4	95.2
12	53.7	87.0	119.0	135.1	141.9	149.4	159.0
13	40.6	59.1	82.2	101.8	104.5	113.3	114.6
14	51.9	75.1	105.4	118.2	129.2	140.7	144.2
15	37.5	59.5	85.3	96.5	106.3	110.9	117.6
16	52.3	70.8	94.1	108.1	115.7	124.7	133.2
17	44.0	60.5	85.3	97.3	107.4	111.9	121.4
18	28.0	49.8	73.0	83.5	92.8	97.8	97.8
19	49.0	71.8	101.6	114.6	128.6	132.8	147.1
20	15.9	23.9	37.0	44.9	44.7	47.1	53.0
21	39.4	57.1	79.2	96.7	105.0	113.3	120.9
22	56.0	85.8	116.2	124.9	136.4	143.0	148.5
23	57.2	75.0	89.2	120.9	128.9	133.4	143.8
24	40.5	57.9	85.5	99.5	110.3	118.1	122.1
25	35.4	51.6	73.4	82.6	90.8	97.5	107.7
26	51.1	69.9	103.8	118.3	128.3	134.3	138.0
27	44.0	58.5	74.1	98.7	98.5	109.3	113.1
28	44.2	65.5	95.7	104.5	113.7	117.4	127.0
29	40.6	62.2	89.5	101.0	109.8	120.3	121.0
30	38.3	61.6	84.6	104.2	112.2	117.9	139.2
31	48.3	73.4	96.0	111.7	114.7	123.3	132.0
32	35.8	53.3	80.6	88.4	100.7	104.8	104.3
33	37.6	64.6	84.6	90.4	99.2	101.2	108.3
34	46.3	68.0	87.2	99.1	103.9	104.4	104.4
35	51.2	84.2	96.0	102.6	112.4	116.1	122.2
36	52.6	99.7	99.0	99.8	108.8	117.3	116.6
37	55.9	88.2	103.3	115.8	117.6	125.1	137.4
38	47.0	82.3	109.5	118.3	120.4	132.9	133.6
39	35.1	64.7	83.3	85.8	97.9	104.3	105.9

TABLE 5

FIRST STAGE k VALUES WITH P^{32}

TWO MOMENT METHOD

RUN NO.	% SEW Dn	CONTROL	Initial Radioactivity-Millicuries per Liter 0.01 / 0.001*	0.1	1.0	10.0
1	4%	.200			.250	
2	5%	.217			.257	
3	5%	.318			.198	
4	4%	.150			.213	
5	4%	.117			.222	
6	4%	.201			.355	
8	4%	.176			.192	
9	4%	.157			.205	
10	4%	.158			.149	
12	4%	.166			.173	
13	4%	.155			.157	
14	4%	.159			.171	
15	4%	.145			.167	
16	4%	.175			.200	
17	4%	.157		.145	.158	.161
18	4%	.132		.149	.122	.128
19	4%	.144		.146	.138	.153
20	5%	.134		.168	.149	.147
21	4%	.131		.159	.168	.053
22	5%	.187		.156	.165	.187
23	4%	.163		.180	.173	.177
24	4%	.136		.125	.128	.142
25	5%	.140		.154	.136	.168
26	4%	.163		.180	.177	.160
27	4%	.163		.135	.143	.171
28	5%	.164		.177	.170	.108
29	4%	.148		.173	.170	.087
30	4%	.111	.133	.124	.131	.101
31	4%	.176	.181*	.181	.168	.164
32	4%	.152	.145*	.161	.138	.123
33	4%	.186		.192	.195	.216
34	4%	.233		.206	.183	.164
35	4%	.234		.257	.246	.220
36	4%	.299		.243	.223	.227
37	4%	.223		.251	.241	.242
38	4%	.192		.181	.197	.188
39	4%	.175		.152	.148	.130
AVERAGE		.174		.173	.183	.159
RUNS 17.-39		.171		.173	.168	.159

TABLE 6

FIRST STAGE L VALUES WITH P^{32}

TWO MOMENT METHOD

RUN NO.	CONTROL	Initial Radioactivity-Millicuries per Liter 0.01 0.001*	0.1	1.0	10.0
1	57.7			56.1	
2	80.2			75.3	
3	101.5			101.5	
4	129.8			124.1	
5	38.5			32.1	
6	67.1			69.1	
8	114.2			110.7	
9	108.4			87.9	
10	103.3			96.8	
12	169.1			168.1	
13	127.1			125.5	
14	156.1			147.3	
15	130.3			125.4	
16	137.1			130.1	
17	129.0		127.9	120.1	123.1
18	115.7		106.6	115.3	115.2
19	158.7		146.2	156.5	149.4
20	58.7		51.7	53.7	55.8
21	136.3		130.5	126.5	195.2
22	155.4		157.0	159.3	149.1
23	151.2		155.2	155.4	151.8
24	139.0		139.3	139.0	130.0
25	116.4		105.6	116.5	101.5
26	150.3		142.3	142.4	142.5
27	120.5		124.3	123.2	112.7
28	134.5		127.8	129.8	146.2
29	135.4		125.2	128.9	150.6
30	159.0	144.3	149.8	143.7	150.1
31	137.2	139.9*	139.7	142.5	137.3
32	118.1	115.8*	115.0	119.9	123.6
33	112.5		187.8	141.7	148.1
34	109.2		120.9	125.4	121.3
35	121.9		118.7	123.8	126.9
36	115.8		116.7	115.9	113.8
37	134.3		102.8	103.6	103.3
38	141.3		135.6	134.1	136.3
39	113.2		117.0	121.3	134.2
AVERAGE	121.2		128.0	118.6	131.2
RUNS 17-39	128.9		128.0		131.2

TABLE 7

FIRST STAGE k VALUES WITH P^{32}

THREE MOMENT METHOD

Initial Radioactivity-Millicuries per Liter

RUN NO.	CONTROL	0.1	1.0	10.0	0.01 0.001*
1	.220		.041		
2	.198		.159		
3	.200		.279		
4	.126		.250		
5	.018		.035		
6	.151		.536		
8	.136		.270		
9	.136		.239		
10	.161		.131		
12	.170		.154		
13	.164		.150		
14	.135		.135		
15	.153		.178		
16	.107		.144		
17	.116	.140	.157	.144	
18	.192	.203	.210	.159	
19	.113	.105	.186	.123	
20	.146	.284	.225	.171	
21	.107	.179	.178	.126	
22	.174	.146	.148	.182	
23	.048	.114	.058	.094	
24	.131	.156	.129	.143	
25	.098	.131	.081	.136	
26	.165	.163	.136	.163	
27	.099	.030	.045	.025	
28	.155	.126	.146	.192	
29	.154	.145	.148	.198	
30	.079	.148	.125	.176	.161
31	.365	.240	.129	.140	.158*
32	.184	.196	.161	.169	.115*
33	.189	.139	.123	.121	
34	.270	.311	.199	.175	
35	.176	.261	.243	.133	
36	.245	.033	.178	.211	
37	.145	.258	.215	.223	
38	.220	.167	.205	.203	
39	.179	.106	.107	.096	
AVERAGE	.157		.169		
(RUNS 17-39)	.163	.164	.154	.152	

TABLE 8

FIRST STAGE L VALUES WITH P^{32}

THREE MOMENT METHOD

RUN	CONTROL	Initial Radoactivity-Millicuries per Liter 0.1	1.0	10.0	0.01 / 0.001*
1	56.7		94.8		
2	81.2		80.5		
3	105.8		96.8		
4	136.1		121.3		
5	117.2		60.3		
6	70.9		70.6		
8	119.9		105.2		
9	111.8		86.0		
10	102.4		100.4		
12	168.3		179.4		
13	124.8		126.4		
14	162.8		156.3		
15	128.4		123.2		
16	156.8		138.8		
17	140.2	129.0	119.9	126.11	
18	105.0	99.3	99.6	107.8	
19	156.7	162.2	145.1	159.0	
20	57.3	47.3	49.1	53.5	
21	145.8	126.8	124.7	139.6	
22	157.1	159.1	163.2	149.8	
23	242.2	174.2	225.2	181.2	
24	140.1	130.2	138.5	129.6	
25	131.1	110.4	139.6	106.8	
26	149.3	144.8	151.2	141.3	
27	139.6	261.8	207.5	273.1	
28	136.2	134.1	134.3	128.1	
29	133.6	130.0	132.8	114.4	
30	182.5	141.6	145.5	124.5	136.4
31	123.6	132.8	152.4	142.5	143.5*
32	111.6	109.9	114.6	112.5	124.3*
33	112.1	201.0	157.3	166.1	
34	116.7	114.6	123.7	119.6	
35	126.9	118.3	123.8	139.5	
36	117.8	225.1	119.8	112.9	
37	144.7	102.7	105.0	104.3	
38	137.7	137.7	132.6	134.2	
39	112.2	131.5	134.2	149.7	
AVERAGE	128.7		126.5		
RUNS 17-39	135.7	140.2	136.5	135.5	

TABLE 9

FIRST STAGE LAG PERIODS* WITH P^{32}

THREE MOMENT METHOD

RUN	CONTROL	Initial Radioactivity-Millicuries per Liter 0.01 / 0.001**	0.1	1.0	10.0
1	0.117			-3.054	
2	-0.124			-0.713	
3	-0.735			0.366	
4	-0.170			0.187	
5	-1.506			-2.786	
6	-0.367			0.641	
8	-0.321			0.368	
9	-0.110			0.175	
10	0.031			-0.114	
12	0.022			-0.241	
13	0.101			-0.034	
14	-0.156			-0.258	
15	0.066			0.070	
16	-0.589			-0.410	
17	-0.318		-0.020	0.004	-0.108
18	0.367		0.311	0.500	0.220
19	0.089		-0.368	0.299	-0.228
20	0.108		0.523	0.414	0.169
21	-0.194		0.131	0.068	0.199
22	-0.088		-0.049	-0.113	-0.035
23	-1.459		-0.566	-1.437	-0.822
24	-0.012		0.225	0.032	0.024
25	-0.389		-0.150	-0.557	-0.232
26	0.028		-0.124	-0.304	0.031
27	-0.595		-1.382	-1.015	-2.169
28	-0.055		-0.340	-0.164	0.048
29	0.054		-0.198	-0.150	0.642
30	-0.344	0.196	0.189	-0.014	0.487
31	0.661	-0.163**	0.304	-0.296	-0.167
32	0.150	-0.243**	0.212	0.163	0.307
33	0.025		-0.398	-0.563	-0.787
34	0.671		0.434	0.078	0.077
35	-0.388		0.025	-0.023	-0.698
36	-0.276		-3.320	-0.297	-0.213
37	-0.581		0.027	-0.154	-0.111
38	0.159		-0.102	0.050	0.084
39	0.042		-0.416	-0.343	-0.323

* in days

TABLE 10

2nd STAGE y VALUES* WITH P^{32}

RUN	DAY 7	8	9	10	12	15	18	20	30
#40									
Control	5.7	2.3	5.1	6.0	19.2	52.9	126.6	129.1	
0.1 mc/l	4.4	6.4	8.0	8.5	17.7	59.8	117.8	123.0	
1.0 mc/l	8.0	8.5	5.9	9.8	36.2	62.7	120.9	120.4	
10.0mc/l	6.0	10.5	18.5	18.5	23.0	28.4	48.5	48.5	
#41									
Control		7.9	8.2	9.5	29.4	60.2	96.4	133.3	155.3
0.1 mc/l	9.7	13.2	20.0	30.4	38.6	65.4	66.2	139.5	154.0
1.0 mc/l	1.3	3.3	9.6	12.0	29.6	128.8	133.2	146.9	167.4
10.0 mc/l	0.9	1.9	7.6	4.6	9.1	11.6	18.4	77.8	132.4
#42									
Control	15.0	17.6	25.7	27.7	32.6	72.9	136.7	139.1	171.9
0.1 mc/l	50.0	49.8	71.0	91.0	114.2	126.3	131.2	138.8	149.3
1.0 mc/l	8.4	11.4	14.7	23.8	64.1	115.7	141.0	146.3	164.3
10.0 mc/l	4.1	22.2	4.6	5.00	6.6	9.1	22.1	40.9	73.1
#43									
Control	2.8	7.3	33.9	54.2	117.0	147.9	156.3	175.3	189.7
0.1 mc/l	4.9	7.1	12.0	11.9	11.1	16.5	18.7	21.9	22.3
1.0 mc/l	4.9	12.1	21.4	40.2	101.8	132.3	133.4	136.1	140.1
10.0 mc/l	1.9	4.3	6.2	8.4	21.2	60.2	123.4	143.5	156.9

*These values do not represent the total BOD exerted by the fresh sewage but were measured on diluted sewage samples which had been allowed to stand under aerobic conditions for six days and then re-aerated before bottling.

TABLE 11

NITRITE-NITROGEN DETERMINATIONS* WITH P^{32}

RUN	DAY	Initial Radioactivity-Millicuries per Liter CONTROL	0.10	1.0	10.0
7	3	0.001		0.001	
7	4	0.001		0.002	
1	6	0.002		0.001	
3**	7	0.015		0.010	
4	7	0.012		0.008	
6	7	0.004		0.006	
10	7	0.005		0.014	
13	7	0.005		0.004	
17	7	0.019	0.016	0.017	0.004
18	7	0.009	0.010	0.013	0.004
19	7	0.012	0.007	0.013	0.008
23	7	0.004	0.006	0.005	0.003
24	7	0.040	0.020	0.022	0.002
25	7	0.035	0.023	0.042	0.001
26	7	0.030	0.014	0.012	0.003
27	7	0.013	0.014	0.015	0.004
28	7	0.032	0.032	0.034	0.0
29	7	0.048	0.048	0.046	0.0
30	7	0.072	0.074	0.080	0.001
31	7	0.028	0.070	0.065	0.002
32	7	0.017	0.020	0.017	0.000
33	7	0.025	0.025	0.025	0.025
34	7	0.025	0.025	0.020	0.000
35	7	0.010	0.017	0.014	0.000
36	7	0.014	0.017	0.010	0.004
37	7	0.007	0.017	0.020	0.004
38	7	0.017	0.017	0.014	0.004
39	7	0.004	0.003	0.002	0.000
AVERAGE		0.023	0.024	0.024	0.004
20	8	0.016	0.019	0.014	0.009
21	8	.190	.160	.200	.001
2**	10	0.070		0.040	
9	10	0.035		0.030	
10	10	0.040		0.014	
22	14	0.076	0.040	0.080	0.060
10	15	0.750		0.950	
2**	16	0.40		0.40	

* PPM in a 4% Dilution
** 5% Dilution

TABLE 12

NITRATE-NITROGEN DETERMINATIONS*WITH P^{32}

RUN	DAY	CONTROL	0.10x	1.0x	10.0x
		Initial Radioactivity-Millicuries per Liter			
17	7	.020	.020	.020	.000
18	7	.010	.010	.010	.000
19	7	.010	.020	.010	.000
23	7	.020	.020	.020	.020
24	7	.010	.015	.010	.010
25	7	.010	.010	.000	.010
26	7	.050	.010	.000	.000
27	7	.010	.000	.000	.000
28	7	.010	.010	.010	.000
29	7	.010	.010	.010	.000
31	7	.010	.010	.010	.000
32	7	.020	.060	.020	.040
33	7	.010	.010	.010	.020
34	7	.020	.010	.020	.010
35	7	.030	.030	.060	.020
36	7	.020	.010	.010	.000
37	7	.020	.030	.020	.020
38	7	.001	.002	.002	.001
39	7	.000	.020	.020	.000
20	8	.020	.010	.010	.005
21	8	.000	.020	.000	.000
22	14	.010	.020	.020	.020
10	10	.010		.015	
2	16	.080		.100	
AVERAGE RUNS 17-39		.015	.015	.014	.008

*NOTE: All values recorded are in p.p.m. for a 4% sewage dilution.

TABLE 13

NITRITE-NITROGEN DETERMINATIONS* WITH p^{32}

RUN	ACTIVITY in mc/l	6	7	8	9	10	12	15	16	18	20	23	31
40	CONTROL		.000	.010	.100	.042	.000		.310	.880	1.020		
	0.1		.005	.200	.065	.030	.080		1.40	.840			
	1.0		.005	.280	.085	.040	.090		.620	.650			
	10.0		.000	.000	.000	.019	.000		.12	.190			
41	CONTROL		.030		.010	.040	.040	.360		.280	.680		
	0.1		.220		.240	.640	.624	.860		.740	.000		
	1.0		.020		.020	.060	.070	.490		.360	.200		
	10.0				.020	.030	.030	.010		.020	.030		
42	CONTROL		.030	.040	.030	.010	.086	.570		.810	.900		.000
	0.1		.690	.540	.560	.440	.010	.000		.000	.000		.000
	1.0		.090	.120	.190	.260	.520	1.160		.000	.110		.000
	10.0		.010	.010	.010	.000	.010	.010		.270	.260		.000
43	CONTROL		.200	.290	.200	.280	.000	.000		.000	.000	.000	
	0.1		.000	.000	.010	.000	.002	.000		.100	.020	.000	
	1.0		.300	.520	.410	.570	.200	.000		.000	.020	.000	
	10.0		.060	.080	.080	.100	.070	.470		1.100	.010	.000	

NITRATE-NITROGEN DETERMINATIONS WITH p^{32}

RUN	ACTIVITY in mc/l	6	7	8	9	10	12	15	16	18	20	23	31
40	CONTROL		.040	.000	.020	.000	.044		.001	.022	.063		
	0.1		.030	.005	.008	.030	.035		.031	.075	.041		
	1.0		.055	.000	.018	.040	.001		.061	.050	.072		
	10.0		.045	.000	.010	.028	.013		.022	.010	.010		
41	CONTROL		.001		.001	.001	.050	.022		.010	.022		
	0.1		.173		.022	.022	.031	.061		.001	.410		
	1.0		.022		.051	.010	.010	.022		.050	.195		
	10.0		.041		.031	.022	.042	.022		.022	.010		
42	CONTROL		.075	.000	.082	.001	.030	.042		.338	.022		.310
	0.1		.076	.031	.031	.115	.380	.460		.620	.380		.198
	1.0		.030	.022	.042	.000	.042	.061		.720	.250		.410
	10.0		.022	.042	.001	.010	.010	.031		.325	.010		.198
43	CONTROL		.200	.290	.200	.280	.000	.000		.000	.000	.000	
	0.1		.000	.000	.010	.000	.002	.000		.100	.020	.000	
	1.0		.300	.520	.410	.570	.200	.000		.000	.020	.000	
	10.0		.060	.080	.100	.070	.470		1.100		.010	.000	

*p.p.m. in a 25% sewage dilution

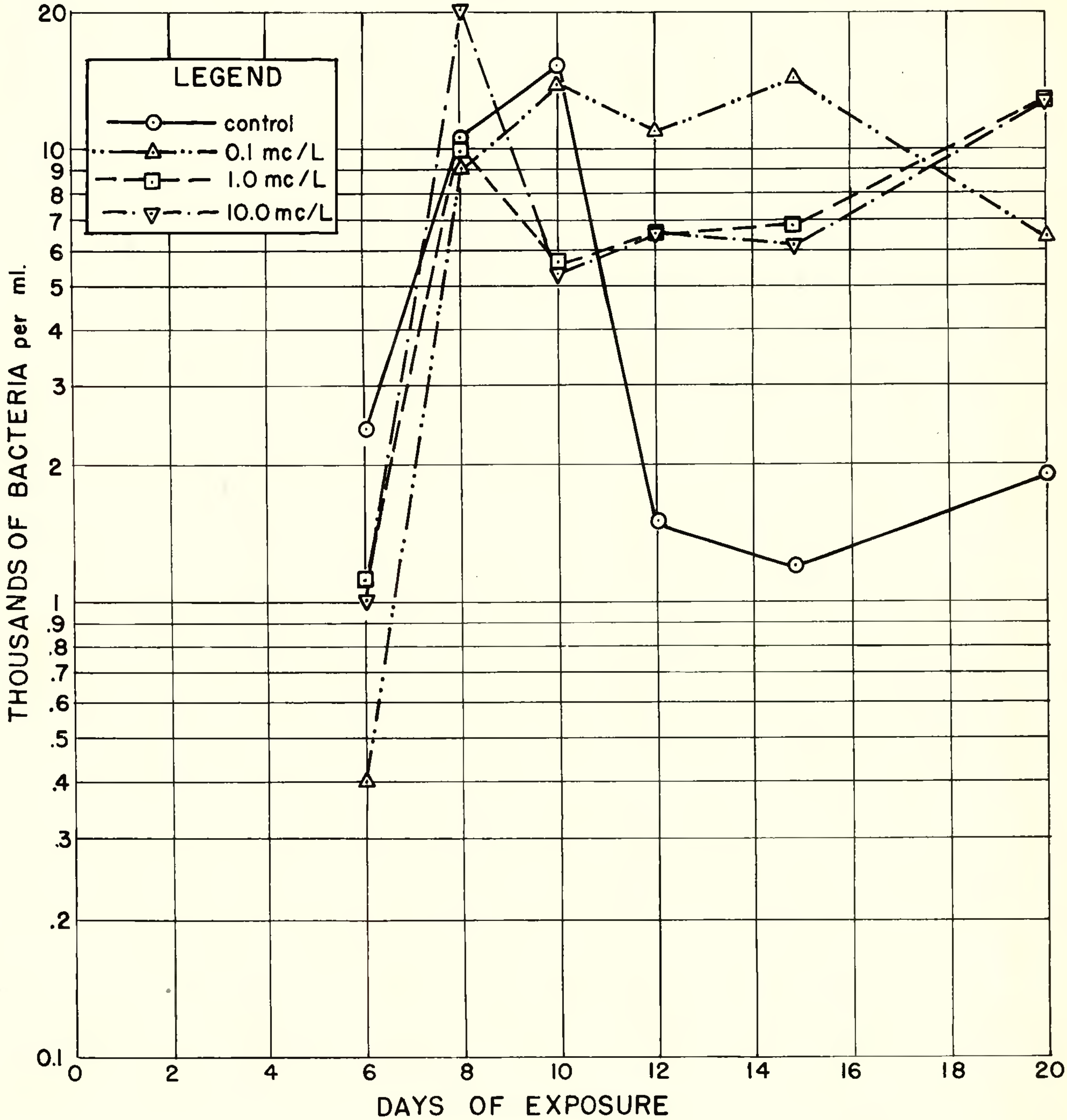

FIG. 9 — BACTERIOLOGICAL DATA — P^{32}
Runs 40,41,42,43
Average Numbers of Bacteria per ml.
Media Tryptone Glucose Extract Agar
Incubation 20 °C, 48 hours

TABLE 14

y VALUES WITH I^{131}

CONTROL

DAY

RUN	1	2	3	4	5	6	7
1	48.8	55.8	70.4	91.1	100.4	124.0	122.3
2	27.9	52.3	72.7	94.0	100.9	100.0	95.9
3	37.1	54.5	78.8	93.5	100.5	106.1	111.4
4	33.9	43.9	64.6	75.1	88.5	90.2	96.4
5	46.3	63.1	78.5	95.2	109.6	119.8	142.3
6	94.0	117.0	168.3	182.7	196.2	203.0	206.0
7	69.3	103.4	123.0	134.0	142.3	148.1	162.4
8	47.3	71.1	83.9	90.9	99.7	110.5	114.2
9	57.0	88.1	112.4	120.0	133.3	138.4	141.2
10	57.0	77.8	100.5	111.5	121.0	126.8	136.8
11	54.5	69.0	89.8	105.1	109.8	116.4	120.9
12	64.3	96.4	119.9	133.7	151.3	164.1	179.1
13	36.8	59.8	77.0	93.3	99.8	110.5	122.1
14	43.8	60.6	78.9	88.7	99.5	107.5	111.3
15	54.7	72.1	88.9	106.4	121.4	133.9	143.1
16	20.2	32.0	47.0	60.3	64.8	69.5	74.1
17	40.9	60.7	79.2	92.9	101.9	108.2	114.8
18	31.0	44.0	63.2	77.1	86.1	83.8	120.3
19	44.8	64.8	91.8	106.0	112.3	117.8	130.6
20	28.9	44.9	56.4	68.6	76.5	71.7	76.7
26	50.7	67.1	87.1	99.7	109.2	114.2	116.7

TABLE 15

y VALUES WITH I^{131}

.01 mc/liter

DAY

RUN	1	2	3	4	5	6	7
5	45.6	60.8	74.3	88.8	106.3	118.1	117.1
6	87.9	111.5	147.8	160.1	166.2	173.7	180.7
7	66.5	98.9	120.9	135.9	137.8	147.3	150.6
14	42.0	58.1	83.9	92.1	101.9	105.9	111.4
15	48.7	64.6	87.3	98.7	108.5	114.7	120.7
16	18.7	31.4	47.7	58.9	61.5	66.2	69.7
17	36.3	53.1	69.4	81.4	84.5	92.2	100.7
18	27.4	39.0	52.7	65.7	69.5	78.5	87.8
19	41.6	62.9	87.4	99.7	109.3	118.5	121.8
20	22.6	34.9	51.9	60.1	63.1	65.1	71.2

0.1 mc/liter

RUN	1	2	3	4	5	6	7
3	39.8	66.6	95.2	105.1	110.4	114.0	113.1
5	42.5	62.8	71.3	83.1	100.9	111.6	113.9
6	92.2	119.6	158.6	173.4	179.9	186.7	194.7
7	64.4	98.4	122.2	131.7	141.0	147.3	152.4
9	57.1	87.5	108.5	120.0	129.3	135.5	137.3
10	50.1	67.7	95.5	101.6	106.9	114.4	120.6
11	40.0	59.6	79.3	86.4	89.5	101.3	108.1
12	63.4	98.9	122.7	133.0	140.3	144.9	155.4
13	35.9	53.2	77.5	86.2	98.2	106.7	112.3
14	40.5	58.8	83.8	90.1	98.7	105.9	108.9
15	51.6	67.0	87.1	101.9	113.4	119.6	125.1
16	20.9	32.4	51.2	61.2	64.0	67.5	72.0
17	38.1	48.9	70.9	81.4	87.7	95.4	99.2
18	27.7	40.7	55.2	70.0	76.0	79.0	83.6
19	41.7	64.9	90.9	102.5	108.3	117.5	125.0
20	22.4	35.6	51.4	61.2	62.4	64.4	70.4

TABLE 16

y VALUES WITH I^{131}

1.0 mc/liter

DAY

RUN	1	2	3	4	5	6	7
1	45.8	62.7	71.3	79.9	81.3	86.2	96.5
2	34.0	54.0	80.3	93.2	103.2	105.7	103.0
4	31.0	54.7	76.0	78.6	87.2	91.7	96.0
5	47.6	64.6	77.9	98.9	108.2	114.4	123.2
6	94.5	114.8	160.8	173.9	182.9	189.7	191.4
7	66.3	102.9	121.7	132.0	135.3	146.5	152.8
9	55.9	83.5	110.5	122.2	128.3	133.5	138.8
10	46.6	69.0	97.2	103.2	109.0	122.0	119.5
11	43.1	59.7	87.7	93.5	96.3	103.6	110.1
12	66.5	97.4	122.7	133.9	140.3	146.9	153.1
13	34.7	54.9	77.2	90.5	96.0	101.0	108.3
14	42.1	59.9	86.2	94.4	102.2	111.4	119.0
15	52.2	68.5	87.6	102.1	114.7	119.9	125.2
16	18.7	32.2	46.5	57.8	62.5	65.1	68.6
17	37.9	49.0	72.2	81.0	86.6	93.1	100.3
18	28.5	42.7	57.7	69.7	78.2	78.3	84.8
19	43.4	63.7	91.0	105.2	111.8	117.6	126.8
20	25.1	36.7	51.5	56.3	58.0	63.0	68.0

10.0 mc/liter

RUN	1	2	3	4	5	6	7
9	58.5	84.8	110.2	122.2	128.7	131.9	132.5
10	45.2	71.0	94.5	100.5	108.0	114.3	120.6
11	40.0	57.5	82.8	88.6	97.6	103.3	107.4
12	64.9	94.8	120.1	130.4	135.3	138.4	145.2
13	35.7	54.5	74.7	87.0	97.0	106.0	112.3

TABLE 17

FIRST STAGE k VALUES WITH I^{131}

TWO MOMENT METHOD

RUN	CONTROL	Initial Radioactivity-Millicuries per Liter 0.001	0.01	0.1	1.0	10.0
1	.129				.254	
2	.142				.151	
3	.143			.185		
4	.134				.168	
5	.116		.146	.150	.160	
6	.215		.247	.240	.241	
7	.227		.236	.224	.239	
8	.203					
9	.206			.214	.205	.230
10	.198			.201	.189	.193
11	.207			.176	.192	.173
12	.160			.221	.227	.243
13	.128			.130	.147	.130
14	.173		.170	.173	.157	
15	.149		.179	.177	.181	
16	.104		.113	.124	.117	
17	.158		.165	.160	.162	
18	.087		.118	.137	.146	
19	.154		.150	.155	.155	
20	.185		.147	.152	.179	
26	.199	0.197				
AVERAGE	.160				.182	

NOTE: A 4% sewage dilution was used for all runs with radio-iodine (I^{131}).

TABLE 18

FIRST STAGE L VALUES WITH I^{131}

TWO MOMENT METHOD

		Initial Radioactivity-Millicuries per Liter				
RUN	CONTROL	0.001	0.01	0.1	1.0	10.0
1	132.7				91.0	
2	116.8				119.5	
3	124.4			124.0		
4	108.5				102.7	
5	154.5		129.6	122.5	129.1	
6	213.0		180.1	195.3	195.5	
7	214.3		204.9	209.2	203.3	
8	157.2					
9	200.2			192.9	195.7	185.3
10	188.6			168.0	175.9	170.8
11	168.2			153.4	155.6	158.2
12	258.3			210.6	208.0	194.7
13	188.5			177.1	166.0	176.2
14	161.8		164.6	160.9	176.4	
15	211.4		174.0	181.0	180.3	
16	126.1		117.0	117.4	114.5	
17	171.7		145.2	148.3	146.6	
18	139.7		98.4	94.3	93.3	
19	138.1		187.5	134.3	136.0	
20	81.5		77.7	76.5	69.8	
26	120.8	153.4				
AVERAGE	165.3				147.7	

TABLE 19

FIRST STAGE k VALUES WITH I^{131}

THREE MOMENT METHOD

RUN	CONTROL	Initial Radioactivity-Millicuries per Liter 0.001	0.01	0.1	1.0	10.0
1	.016				.094	
2	.281				.227	
3	.148			.272		
4	.106				.187	
5	.001		.068	.057	.083	
6	.187		.174	.183	.200	
7	.134		.199	.189	.172	
8	.107					
9	.187			.192	.196	.241
10	.118			.153	.184	.170
11	.136			.111	.164	.157
12	.075			.181	.186	.218
13	.085			.109	.152	.103
14	.107		.129	.156	.117	
15	.046		.119	.106	.109	
16	.123		.156	.162	.160	
17	.120		.105	.117	.112	
18	.001		.056	.133	.139	
19	.124		.139	.142	.142	
20	.208		.163	.177	.141	
26	.145	.134				

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TABLE 20

FIRST STAGE L VALUES WITH I^{131}

THREE MOMENT METHOD

Initial Radoactivity-Millicuries per Liter

RUN	CONTROL	0.001	0.01	0.1	1.0	10.0
1	451.7				110.8	
2	101.3				109.9	
3	123.1			116.5		
4	117.1				100.3	
5	6211.8		170.4	178.0	159.6	
6	217.6		189.2	202.8	200.1	
7	174.7		156.0	158.4	159.2	
8	133.3					
9	148.5			144.0	144.0	136.7
10	154.7			129.2	127.5	127.0
11	133.9			124.8	116.3	116.2
12	238.4			160.0	158.9	147.8
13	157.5			135.1	117.7	137.2
14	132.7		127.1	118.5	1137.3	
15	244.9		138.8	149.3	148.3	
16	87.0		76.6	78.0	75.2	
17	132.5		118.5	116.0	116.7	
18	5313.0		138.1	95.2	94.6	
19	147.1		137.1	137.4	139.3	
20	79.7		75.8	73.8	73.8	
26	128.8	166.7				

TABLE 21

FIRST STAGE LAG PERIODS* WITH I^{131}

THREE MOMENT METHOD

RUN	CONTROL	Initial Radioactivity-Millicuries per Liter				
		0.001	0.01	0.1	1.0	10.0
1	-1.663				-1.638	
2	0.630				0.406	
3	0.040			0.400		
4	-0.239				0.109	
5	-2.230		-0.775	-1.084	-0.774	
6	-0.185		-0.496	-0.383	-0.258	
7	-0.745		-0.227	-0.229	-0.467	
8	-0.883					
9	-0.132			-0.138	-0.67	0.056
10	-0.678			-0.357	-0.036	-0.153
11	-0.559			-0.577	-0.192	-0.119
12	-0.882			-0.263	-0.283	-0.151
13	-0.387			-0.175	0.043	-0.237
14	-0.583		-0.305	-0.123	-0.329	
15	-1.299		-0.498	-0.631	-0.637	
16	0.166		0.295	0.252	0.300	
17	-0.301		-0.533	-0.357	-0.428	
18	-1.590		-0.666	-0.015	-0.045	
19	-0.233		-0.078	-0.086	-0.080	
20	0.135		0.106	0.155	-0.286	
26	-0.398	-0.493				

* in days

TABLE 22

2nd STAGE y VALUES* WITH I^{131}

* See note on Table 10

RUN	DAY 8	9	10	12	14	16	19	22	26	30
#21										
Control	11.0	18.7	26.4	34.8	84.4	139.1	147.3	172.7	177.7	174.4
.01 mc/l	14.0	16.6	22.4	36.4	38.2	88.8	146.8	170.5	198.2	208.3
0.1 mc/l	11.4	14.4	20.2	30.6	31.9	62.9	136.3	168.0	182.3	183.4
1.0 mc/l	2.4	5.5	9.9	15.0	23.0	54.8	119.9	155.9	159.3	163.7
#22										
Control	22.7	39.5	58.1	94.1	102.9	121.2	134.9	135.0	136.3	135.1
.01 mc/l		6.8	13.1	28.4	65.1	108.1	122.9	129.6	159.6	170.3
0.1 mc/l	1.1	11.8	18.1	30.1	90.9	113.6	121.6	156.3	161.7	169.4
1.0 mc/l		3.3	9.3	23.6	67.4	108.4	143.7	156.9	158.6	159.0
#23										
Control	13.6	20.4	21.5	27.2	32.5	38.8	39.4	42.4	39.5	50.7
.01 mc/l	6.0	12.2	15.5	27.1	34.4	52.4	106.4	128.7	143.5	144.5
0.1 mc/l	2.6	3.4	5.0	13.8	33.3	53.0	107.4	111.4	109.9	115.4
1.0 mc/l					14.2	77.4	86.7	95.0	95.7	96.5
#24										
Control	8.7	16.7	17.8	49.1	87.4	148.6	199.7	233.7	236.1	244.6
.01 mc/l	12.1	16.1	20.1	30.5	46.2	91.2	168.1	193.1	229.1	238.8
0.1 mc/l	4.2	10.2	11.9	21.7	67.0	150.7	175.4	185.8	212.4	217.5
1.0 mc/l	14.4	13.2	18.9	24.2	30.9	65.9	189.0	170.8	172.6	201.9
#25										
Control	7.0	12.4	19.4	50.1	115.8	137.8	198.8	213.5	205.2	207.2
.01 mc/l	7.6	12.0	13.7	26.1	48.4	100.0	206.2	214.5	259.9	264.9
0.1 mc/l	3.7	3.8	9.4	18.1	48.8	86.8	140.4	156.4	190.5	198.8
1.0 mc/l	5.0	10.0	8.5	14.2	34.2	61.2	131.5	156.2	172.9	191.2

TABLE 23

NITRITE-NITROGEN DETERMINATIONS* WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	1	2	3	4	5	6	7
7	CONTROL	.035	.025	.020	.001	.005	.060	.010	.195
	.01	.000	.025	.025	.000	.000	.035	.001	.020
	0.1	.000	.020	.015	.000	.000	.030	.005	.020
	1.0	.000	.025	.015	.000	.000	.035	.010	.005
9	CONTROL			.060	.070	.080	.030	.080	1.14
	0.1			.060	.040	.040	.020	.060	.120
	1.0			.060	.040	.060	.010	.070	.110
	10.0			.100	.070	.090	.070	.140	.230
10	CONTROL		.020	.090	.080	.100	.030	.060	.130
	0.1		.020	.080	.060	.080	.010	.200	.060
	1.0		.040	.090	.090	.080	.030	.040	.090
	10.0		.010	.260	.260	.200	.180	.020	.260
11	CONTROL		.120	.100	.080	.080	.080	.043	.150
	0.1		.120	.100	.060	.040	.040	.038	.230
	1.0		.120	.120	.080	.040	.040	.020	.220
	10.0		.230	.230	.180	.160	.140	.040	.220
12	CONTROL		.220	.190	.210	.247	.600	.940	1.24
	0.1		.170	.080	.060	.045	.060	.080	.130
	1.0		.160	.110	.100	.085	.060	.080	.130
	10.0		.230	.150	.120	.100	.120	.130	.110
13	CONTROL		.020	.120	.100	.070	.050	.080	.060
	0.1		.110	.100	.030	.070	.060	.090	.150
	1.0		.110	.090	.040	.060	.050	.080	.120
	10.0		.260	.260	.140	.100	.190	.200	.240
14	CONTROL		.160	.120	.080	.060	.190	.280	.110
	.01		.160	.090	.060	.080	.080	.130	.120
	0.1		.120	.080	.040	.060	.070	.130	.110
	1.0		.090	.090	.040	.070	.070	.140	.120
15	CONTROL		.240	.160	.190	.270	.220	.580	1.14
	.01		.180	.160	.160	.170	.080	.080	.130
	0.1		.170	.160	.170	.150	.080	.090	.130
	1.0		.150	.170	.150	.200	.090	.100	.160
16	CONTROL		.110	.125	.130	.110	.130	.200	.330
	.01		.085	.095	.065	.040	.050	.050	.040
	0.1		.125	.075	.063	.060	.040	.045	.060
	1.0		.110	.110	.100	.096	.050	.040	.090
17	CONTROL		.145	.050	.079	.080	.090	.120	.250
	.01		.120	.060	.081	.050	.060	.060	.070
	0.1		.120	.060	.061	.030	.060	.050	.080
	1.0		.100	.070	.081	.050	.060	.060	.100

(continued)

TABLE 23 (Cont'd)

NITRITE-NITROGEN DETERMINATIONS*WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	1	2	3	4	5	6	7
18	CONTROL		.120	.110	.182	.450	.242	.110	.250
	.01		.170	.140	.182	.182	.146	.079	.120
	0.1		.180	.182	.196	.270	.170	.100	.130
	1.0		.160	.200	.280	.368	.200	.150	.180
19	CONTROL	.200	.180	.140	.140	.145	.190	.145	.230
	.01	.170	.190	.140	.130	.140	.170	.140	.160
	0.1	.170	.165	.130	.120	.150	.150	.155	.190
	1.0	.190	.190	.155	.130	.140	.160	.170	.200
20	CONTROL	.170	.155	.100	.040	.020	.170	.155	.680
	.01	.160	.150	.100	.040	.025	.180	.180	.170
	0.1	.170	.160	.090	.030	.015	.170	.150	.120
	1.0	.160	.160	.110	.040	.010	.170	.155	.200

*p.p.m. in a 4% sewage dilution.

TABLE 24

NITRATE-NITROGEN DETERMINATIONS*WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	1	2	3	4	5	6	7
7	CONTROL	.030	.070	.043	.030	.030	.025	.045	.035
	.01	.044	.015	.010	.012	.013	.020	.012	.010
	0.1	.032	.012	.012	.010	.012	.015	.012	.010
	1.0	.032	.021	.010	.010	.010	.022	.015	.035
9	CONTROL		.050	.070	.080	.090	.090	.040	.055
	0.1		.020	.020	.050	.050	.025	.025	.010
	1.0		.020	.020	.050	.050	.010	.015	.010
	10.0		.020	.030	.060	.060	.030	.015	.020
10	CONTROL		.010	.020	.030	.030	.020	.010	.020
	0.1		.010	.010	.020	.020	.020	.050	.030
	1.0		.005	.010	.010	.030	.020	.020	.035
	10.0		.005	.050	.040	.075	.070	.010	.090
11	CONTROL		.020	.030	.035	.040	.020	.030	.025
	0.1		.040	.025	.040	.030	.020	.030	.025
	1.0		.040	.020	.030	.030	.030	.034	.015
	10.0		.040	.020	.030	.030	.070	.035	.020
12	CONTROL		.025	.044	.045	.109	.035	.065	.120
	0.1		.025	.025	.023	.020	.020	.035	.020
	1.0		.020	.025	.024	.045	.015	.030	.015
	10.0		.040	.023	.030	.040	.020	.030	.010
13	CONTROL		.055	.030	.040	.080	.055	.030	.055
	0.1		.020	.020	.000	.025	.030	.025	.015
	1.0		.020	.025	.025	.030	.025	.035	.030
	10.0		.020	.025	.010	.035	.040	.030	.030
14	CONTROL		.070	.025	.040	.045	.060	.050	.018
	.01		.025	.025	.020	.030	.025	.020	.022
	0.1		.020	.025	.020	.025	.035	.020	.020
	1.0		.030	.020	.015	.030	.030	.025	.015
15	CONTROL		.008	.050	.040	.030	.038	.045	.040
	.01		.018	.040	.040	.020	.030	.010	.025
	0.1		.015	.035	.025	.025	.030	.010	.025
	1.0		.018	.030	.035	.030	.035	.033	.030
16	CONTROL		.035	.022	.030	.028	.045	.023	.050
	.01		.020	.023	.034	.031	.016	.010	.015
	0.1		.020	.029	.034	.023	.016	.005	.022
	1.0		.028	.019	.029	.039	.022	.019	.015
17	CONTROL		.042	.035	.020	.030	.020	.038	.034
	.01		.022	.034	.030	.027	.015	.025	.027
	0.1		.025	.027	.025	.030	.025	.025	.030
	1.0		.025	.030	.027	.040	.030	.044	.034
18	CONTROL		.010	.035	.052	.012	.012	.030	.045
	.01		.030	.027	.019	.010	.015	.020	.250
	0.1		.035	.025	.031	.014	.017	.027	.250
	1.0		.027	.031	.050	.015	.015	.036	.040

(continued)

TABLE 24 (Cont'd)

NITRATE-NITROGEN DETERMINATIONS* WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	1	2	3	4	5	6	7
19	CONTROL		.020	.025	.030	.045	.065	.035	.040
	.01		.015	.018	.050	.060	.072	.035	.025
	0.1		.010	.020	.040	.055	.060	.035	.020
	1.0		.015	.015	.040	.045	.070	.030	.030
20	CONTROL		.020	.055	.040	.020	.035	.030	.020
	.01		.020	.045	.025	.030	.025	.030	.015
	0.1		.015	.040	.020	.025	.010	.025	.010
	1.0		.015	.045	.025	.010	.020	.035	.015

*p.p.m. in a 4% sewage dilution.

TABLE 25

AMMONIA-NITROGEN DETERMINATIONS* WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	1	2	3	4	5	6	7
13	CONTROL		.125	.438	.125	.250	.625	.813	.400
	0.1		.188		.405	.625	.625	.500	.938
	1.0		.185		.500	.500	.750	.938	.875
	10.0		.125		.065	.250	.625	.875	.813
14	CONTROL		1.50	1.75	2.00	2.40	1.25	1.85	1.63
	.01		1.19	1.55	2.00	2.30	2.40	2.50	2.00
	0.1		1.06	1.38	2.00	2.10	2.00	2.20	2.00
	1.0		.750	.900	1.13	1.20	1.75	2.63	.800
15	CONTROL	.130	.125	.010	1.00	.630	.875	.500	.375
	.01	.630	.250	.125	.870	.875	.500	1.38	1.00
	0.1	.875	.375	.010	.900	.950	.250	1.00	.875
	1.0	1.10	.255	.010	.400	.875	.375	.400	.950
16	CONTROL		.125	.360	.350	.250		1.39	.005
	.01		.500	.875	.520	.380	1.37	.750	.013
	0.1		.520	.800	.350	.360	1.05	1.030	.038
	1.0		.625	.750	.520	.500	.630	1.60	.005
17	CONTROL		.038	.030	.013	.038			.155
	.01		.019	.075	.080	.108			.013
	0.1		.013	.025	.088	.060			.038
	1.0		.019	.037	.001	.063			.100
18	CONTROL		.025	.300	.010	.250	.300	1.00	.050
	.01		.045	.660	.375	1.05	.250	1.50	.075
	0.1		.030	.500	.660	.660	.880	1.25	.065
	1.0		.038	.440	.600	.580	.550	.375	.045
19	CONTROL	.063	.063	.063	.069	.690	1.08	.118	3.88
	.01	.063	.063	.069	.061	.750	1.63	.069	1.85
	0.1	.063	.069	.088	.069	.630	.870	.102	1.55
	1.0	.060	.050	.060	.075	.750	.950	.113	.920
20	CONTROL	.040	.190	.050	.250	.050	.020	.190	1.25
	.01	.372	.380	.100		.600	.250	.500	.370
	0.1	.190	.300	.100		.600	.250	.500	.370
	1.0	.100	.250	.190	.200	.380	.030	.100	.750

* p.p.m. in a 4% sewage dilution

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TABLE 26

NITRITE-NITROGEN DETERMINATIONS* WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	6	8	9	10	12	14	16	19	22	26	30	35
21	CONTROL		.020	.030	.041	.105	.168	.580	.934	.009	.003	.004	.003	
	.01		.027	.013	.019	.024	.037	.135	.188	1.18	1.08	.007	.004	
	0.1		.025	.016	.016	.017	.037	.058	.672	1.09	.007	1.16	.005	
	1.0		.016	.015	.017	.022	.050	.117	.318	.939	.003	.007	.006	
22	CONTROL		.117	.055	.354	.375	.014	.008	.014	.028	.101	.001	.010	
	.01		.011	.500	.043	.074	.142	.445	.814	.950	.900	.793	.010	
	0.1		.019	.063	.054	.067	.139	.710	.838	.885	.005	.006	.011	
	1.0		.058	.178	.172	.182	.223	.469	.620	.021	.006	.007	.011	
23**	CONTROL		.035	.014	.009	.007	.001	.007	.008	.007	.071	.008	.006	
	.01		.009	.006	.017	.017	.044	.200	.363	.824	.655	.004	.008	
	.10		.011	.008	.027	.029	.108	.553	.398	.017	.042	.007	.011	
	1.0		.030	.038	.006	.076	.196	.535	.011	.021	.042	.006	.011	
24	CONTROL	.020	.014	.027	.054	.099	.004	.939	1.38	.911	.001	.010	.011	.003
	.01	.020	.019	.027	.043	.071	.205	.911	.795	1.06	.342	1.06	.006	.000
	.10	.020	.017	.022	.024	.036	.135	.885	1.24	1.23	.001	.019	.008	.003
	1.0	.024	.020	.026	.020	.032	.081	.335	.430	1.63	1.71	.199	1.38	.025
25	CONTROL	.041	.020	.108	.105	.102	.342	.655	1.12	1.03	.031	.008	.001	.029
	.01	.055	.010	.022	.024	.050	.063	.182	1.63	1.63	1.63	1.63	.006	.035
	.10	.029	.013	.025	.030	.039	.105	.179	.838	1.09	1.27	.027	.001	.024
	1.0	.031	.011	.020	.022	.041	.047	.177	.469	1.03	1.16	.010	.004	.065

*p.p.m. in a 3% sewage dilution

**4% sewage dilution

TABLE 27

NITRATE-NITROGEN DETERMINATIONS* WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	6	8	9	10	12	14	16	19	22	26	30	35
21	CONTROL		.108	.110	.040	.016	.029	.052	.094	.088	.500	.594	.249	
	.01		.044	.038	.029	.012	.018	.027	.020	.038	.024	.722	.445	
	0.1		.032	.040	.029	.016	.016	.024	.016	.052	.229	.049	.353	
	1.0		.033	.027	.027	.016	.024	.033	.022	.042	.242	.576	.424	
22	CONTROL			.068	.211	.132	.217	.469	.134	.512	.528	.354	.114	
	.01			.088	.022	.052	.020	.027	.031	.358	.442	.201	.605	
	0.1			.029	.012	.043	.057	.042	.038	.336	.528	.540	.530	
	1.0			.029	.035	.045	.065	.057	.073	.528	.632	.760	.722	
23**	CONTROL		.097	.206	.104	.612	.242	.301	.403	.382	.242	.109	.101	
	.01		.039	.084	.017	.033	.027	.024	.057	.708	.048	.188	.410	
	0.1		.037	.074	.016	.031	.033	.020	.018	.400	.070	.158	.201	
	1.0		.038	.020	.022	.029	.045	.073	.297	.312	.170	.176	.236	
24	CONTROL	.061	.040	.051	.029	.033	.612	.082	.049	.062	.696	.424	.895	1.28
	.01	.024	.025	.023	.020	.017	.022	.038	.069	.075	.576	.049	.835	1.12
	0.1	.104	.029	.063	.167	.034	.022	.079	.069	.032	.558	.177	.835	1.00
	1.0	.086	.031	.022	.020	.020	.022	.063	.049	.016	.075	.249	.261	1.32
25	CONTROL	.042	.024	.031	.016	.020	.024	.027	.024	.044	.576	.410	.395	.313
	.01	.031	.018	.016	.020	.024	.006	.012	.047	.032	.061	.155	.700	.620
	0.1	.015	.031	.020	.018	.022	.027	.006	.018	.032	.062	.486	.550	.236
	1.0	.014	.020	.016	.018	.020	.016	.004	.035	.020	.896	.502	.680	.326

* p.p.m. in a 3% sewage dilution

**4% sewage dilution

TABLE 28

AMMONIA-NITROGEN DETERMINATIONS*WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	6	8	9	10	12	14	16	19	22	26	30	35
21	CONTROL		.200	.360	.100	.147	.300	185	920	.055	.093	.130	.021	
	.01		.630	1.18	.170	.460	.850	.580	.430	.093	.093	.055	.000	
	0.1		.500	.590	.080	.340	.300	.380	.111	.111	.111	.055	.037	
	1.0		.930	.360	.180	.261	.380	.420	.425	.131	.093	.093	.112	
22	CONTROL		.380	1.55	.131	.112	.074	.190	.174	.190	.019	.314	.495	
	.01		.340	.110	1.15	.273	1.11	.170	.055	.046	.000	.000	.170	
	0.1		.460	.223	1.18	.210	.875	.131	.074	.037	.000	.019	.170	
	1.0		.460	.223	.890	.190	.790	.131	.131	.046	.000	.019	.190	
23**	CONTROL		.920	.131	.020	.055	.150	.180	.251	.358	.315	.112	.131	
	.01		.369	1.25	.115	.293	1.18	.645	.141	.150	.170	.150	.170	
	0.1		.347	.750	.775	.073	.645	.112	.131	.172	.190	.150	.150	
	1.0		.358	.590	.750	.112	.325	.964	.112	.270	.890	.190	.150	
24	CONTROL	1.57	2.29	2.05	2.28	2.28	.380	.615	.520	.112	.131	.160	.112	.112
	.01	2.11	2.69	2.61	2.28	2.65	2.57	.615	1.29	.112	.112	.160	.055	.112
	0.1	2.09	2.50	.240	2.28	2.43	2.82	.565	.190	.150	.150	.160	.112	.112
	1.0	2.33	3.09	2.50	2.73	2.61	3.09	3.00	2.50	.170	.170	.251	.112	.112
25	CONTROL	.694	1.07	.170	1.44	1.15	.670	.230	.131	.160	.064	.000	.093	.055
	.01	1.06	2.36	3.15	2.90	2.25	2.73	2.25	.150	.190	.055	.000	.037	.055
	0.1	.835	1.57	1.84	1.36	1.52	1.84	.950	.150	.230	.055	.000	.037	.050
	1.0	1.11	1.33	1.48	1.64	1.22	1.70	.495	1.22	.160	.053	.007	.093	.050

* p.p. m. in a 3% sewage dilution

**4% sewage dilution

TABLE 29

pH DETERMINATIONS WITH I^{131}

RUN	ACTIVITY in mc/l	DAY 0	6	8	9	10	12	14	16	19	22	26	30	35
21	CONTROL		7.00	6.85	6.81	6.71	6.58	6.24	6.15	6.25	6.05	6.00	5.93	
	.01		6.91	6.85	6.79	6.74	6.56	6.36	6.30	5.90	5.75	5.80	5.85	
	0.1		6.81	6.81	6.76	6.72	6.65	6.44	6.10	5.99	5.82	5.80	5.90	
	1.0		6.88	6.84	6.77	6.74	6.65	6.62	6.37	6.08	5.90	5.90	5.95	
22	CONTROL		6.42	6.74	6.20	6.15	6.02	6.15	6.08	5.95	6.40	6.15	6.00	
			6.54	6.37	6.45	6.42	6.44	6.42	5.94	5.92	5.90	5.85	5.90	
			6.50	6.55	6.40	6.40	6.45	6.10	5.95	5.95	5.90	5.90	5.90	
			6.61	6.64	6.42	6.40	6.36	6.24	6.01	6.00	5.94	5.95	6.00	
23	CONTROL		6.00	6.22	6.04	6.12	6.10	6.20	6.06	6.05	6.00	6.00	6.32	
	.01		6.38	6.35	6.29	6.32	6.30	6.17	6.12	5.82	5.80	5.75	5.65	
	0.1		6.43	6.44	6.33	6.40	6.36	6.17	6.10	5.95	6.00	5.90	5.90	
	1.0		6.56	6.40	6.35	6.42	6.30	6.05	6.03	5.95	6.00	5.95	5.96	
24	CONTROL	6.65	6.55	6.45	6.46	6.60	6.05	6.30	6.05	5.95	6.35	6.17	6.60	6.55
	.01	6.65	6.51	6.50	6.50	6.45	6.15	6.15	6.20	5.97	6.95	6.00	6.00	6.10
	0.1	6.65	6.51	6.50	6.50	6.45	6.45	6.20	6.05	6.96	6.00	6.05	6.00	5.95
	1.0	6.65	6.52	6.46	6.50	6.45	6.45	6.35	6.30	5.90	6.05	6.00	6.05	6.00
25	CONTROL	6.44	6.70	6.25	6.30	6.28	6.10	6.05	5.73	5.80	6.31	6.45	6.05	6.30
	.01	6.45	6.45	6.30	6.28	6.30	6.25	6.24	5.48	5.55	5.60	5.50	5.50	5.60
	0.1	6.50	6.45	6.38	6.35	6.29	6.28	6.27	5.85	5.70	5.82	5.70	5.62	5.65
	1.0	6.45	6.50	6.40	6.30	6.26	6.30	6.60	6.00	5.80	5.90	5.85	5.75	5.70

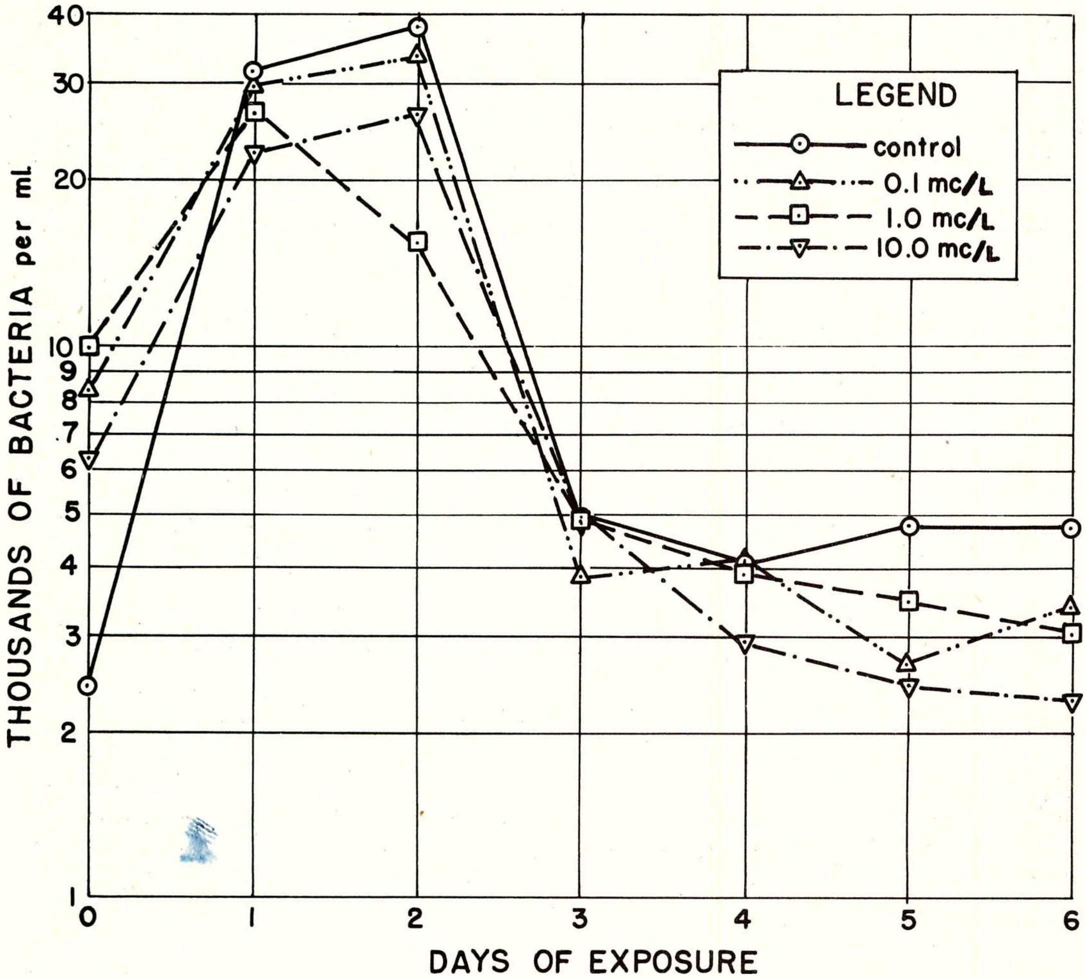

FIG. 10 – BACTERIOLOGICAL DATA – I^{131}

Runs 10, 11, 12, 13

Average Numbers of Bacteria per ml.

Media – Tryptone Glucose Extract Agar

Incubation 20° C, 48 hours

was the variation in the time at which the samples were analyzed. The values of t used in the curve fitting computations were always taken as even days although the actual times at which the dissolved oxygen determinations were made were as much as three hours different from the even day in some instances. However, these errors were practically the same for all activity levels since all of the samples to be analyzed on any one day were "winklerized" at essentially the same time.

B. Effect of Radioactivity on the First Stage BOD

The average y values, i.e. BOD values, obtained at the various levels of radioactivity are shown in Figures 11, 12 and 13. On each figure all of the points plotted were obtained from the same set of runs and are therefore comparable with each other. There were only five runs which included all levels of activity with I^{131}, as shown by Figure 12. In order to include the more extensive results obtained at lower levels with I^{131} Figure 13 is presented. No attempt was made to fit average curves to the plotted points since it is believed that such curves would have no great significance. The points have been merely connected by straight lines in order to show the comparative trends. Since the results shown by each of the figures came from a given set of runs, any divergences noted between the different levels of radioactivity must be due to experimental errors and real effects caused by the radioactivity or to both.

It is apparent from Figure 11 that there was very little divergence on the average between the y value obtained for the control runs and the 0.1 and 1.0 mc/l levels with P^{32}. There appears to have been a definite but slight lowering of the BOD at the 10.0 mc/l level of P^{32}. The results suggest the P^{32} was beginning to exert an effect at the 10.0 mc/l level and that higher levels of activity may produce greater divergences.

Figures12 and 13 indicate that on the average I^{131} exerted a considerable effect on the reaction. All of the average y values obtained with the radioactive samples were considerably lower than those of the control samples. There appears to have been little difference in the results at the various levels of activity but some consistency is to be noted in these differences. As compared to the control samples the 1.0 activity level had the least effect and the effects at the 0.01 and the 10.0 levels appear to have been about equal.

C. Statistical Treatment of Data

It would appear to be highly improbable that the consistent divergences noted between the average y values could have been due to the chance factor of experimental errors. To obtain a measure of this probability the data have been analyzed statistically. The two statistical techniques that were utilized were Student's "t" test and the analysis of variance. The "t" test enables the parameters at any two levels of activity to be compared whereas the analysis of variance compares all levels with each other. Since these techniques can be applied with validity only to samples drawn from normally distributed populations, the normality of the data has itself been tested. The results indicate that the assumption of normality is valid. In applying the "t" test the variable in each instance was the difference in the value of the parameter as obtained for the "hot" and "cold" sewages. The hypothesis was made that the mean difference is zero, i.e., that there is no real difference due to the radioactivity and that the variations from run to run are completely attributable to other factors.

The analysis of variance is a statistical technique designed to separate the variations in the parameter being tested into several components, each corresponding to a separate source of variation. The values

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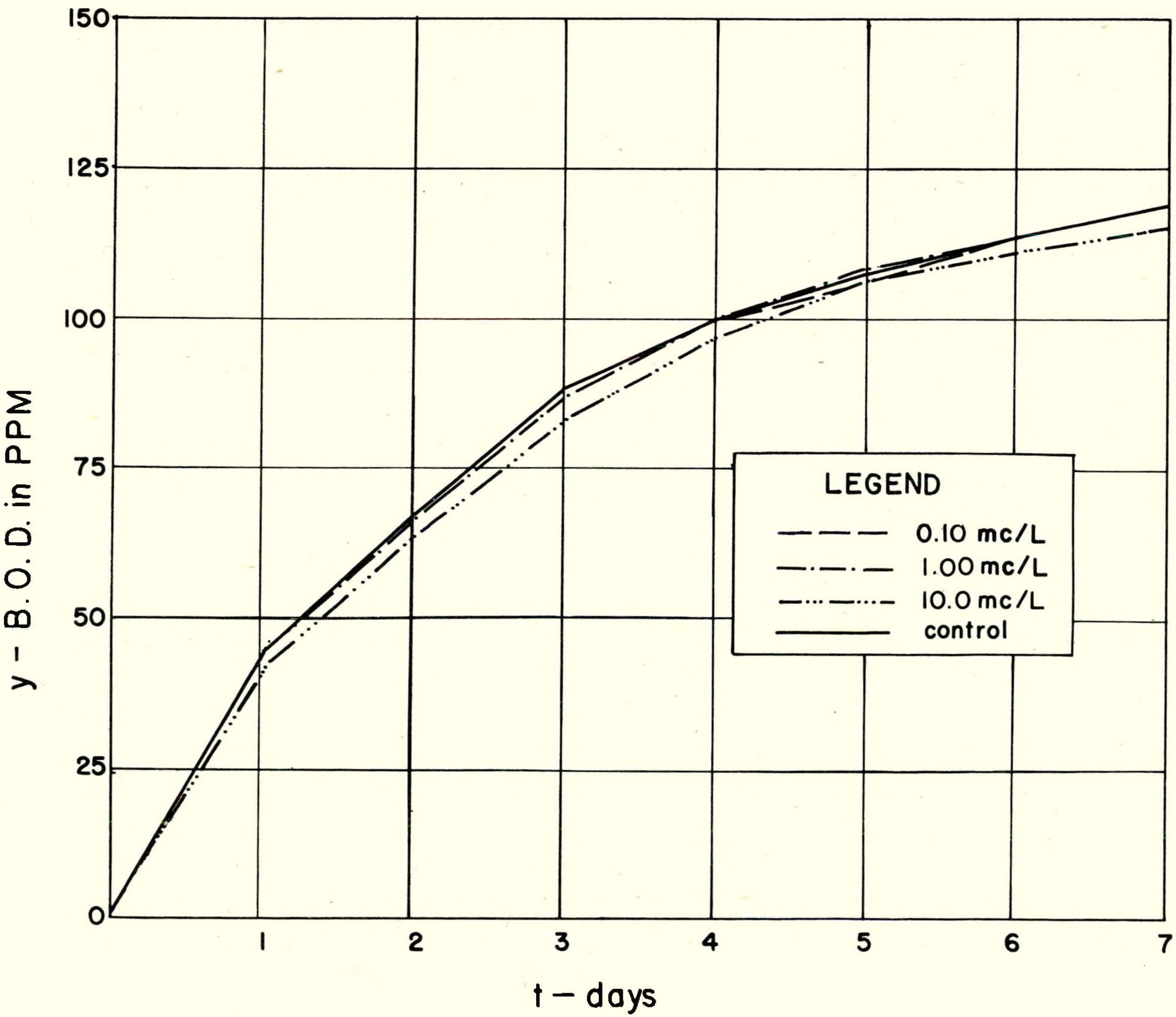

FIG. 11 — y Values with P^{32}, Averages of Runs 17–29, and 33–39

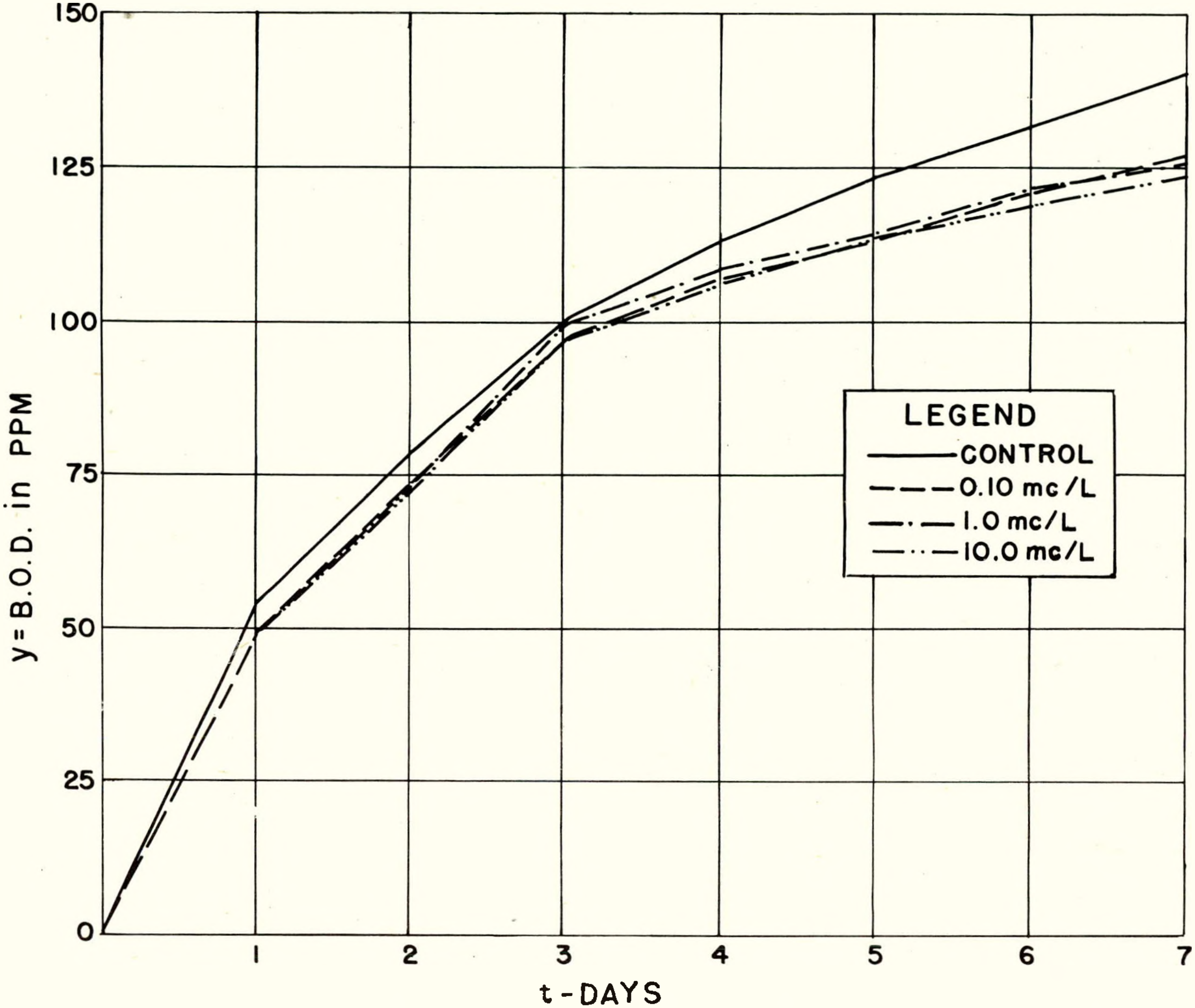

FIG. 12 — y Values with I^{131}, Averages of Runs 9–13 Inclusive

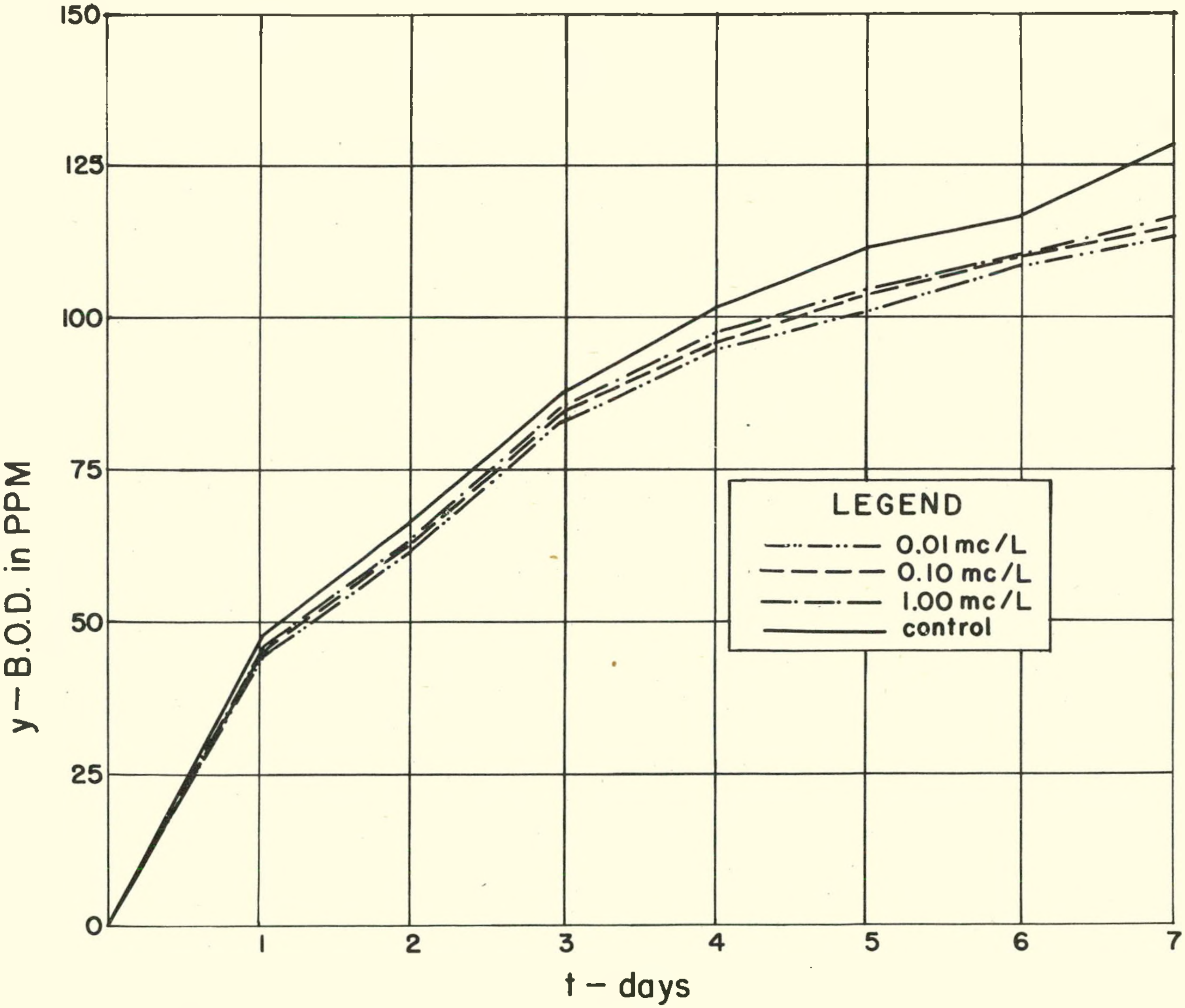

FIG. 13 — y Values with I^{131}, Averages of Runs 5-7, 14-19

are arranged in a table each row of which contains all values obtained for a given run and each column of which contains the values for a given level of radioactivity. The sum of the squared deviations from the overall mean is divided into three components, one being a measure of the variation from row to row, the second a measure of the variation between columns and the residual being a measure of the variation due to experimental errors. The hypothesis tested is that the variable is independent of the criteria used for the classification. This technique utilizes the "F" distribution. Sample calculations for these tests are given in the appendix.

D. Effect of P^{32} on the First Stage BOD

The results of the t tests applied to the first stage parameters obtained with P^{32} are given in table 30. The tests were applied to the 5 and 7 day y values and to the k and L values as obtained by the two moment fit of the unimolecular curve. In each instance the value of $\bar{d}$ in the table is the mean difference between the parameters measured for the "hot" and "cold" samples and P is the probability of obtaining by chance alone a value of $\bar{d}$ equal to or greater than that actually observed. For example, the mean difference between the 5 day BOD of the control samples and the samples at the 10.0 mc/l level was found to be 1.[illegible]8 parts per million and the corresponding value of P is 38.5 per cent. This is interpreted to mean that, if the null hypothesis is true, i.e., if the mean of all possible values for $\bar{d}$ is zero, a value of $\bar{d}$ equal to or greater in magnitude than 1.[illegible]8 would be obtained 38.5 per cent of the time by chance alone from repeated experiments of 23 runs. This particular result indicates that one could not confidently attribute the difference to the are arranged in a table each row of which contains all values obtained for a given run and each column of which contains the values for a given level of radioactivity. The sum of the squared deviations from the overall mean is divided into three components, one being a measure of the variation from row to row, the second a measure of the variation between columns and the residual being a measure of the variation due to experimental errors. The hypothesis tested is that the variable is independent of the criteria used for the classification. This technique utilizes the "F" distribution. Sample calculations for these tests are given in the appendix.

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TABLE 30

RESULTS OF "t" TEST ON FIRST STAGE BOD PARAMETERS OBTAINED WITH P^{32}

RADIOACTIVITY IN mc/1	NO. OF RUNS	5 - DAY BOD $\bar{d}=\frac{\sum(y_s-y_c)}{n}$	5 - DAY BOD % P	7 - DAY BOD $\bar{d}=\frac{\sum(y_s-y_c)}{n}$	7 - DAY BOD % P	2 - MOMENT k $\bar{d}=\frac{\sum(k_s-k_c)}{n}$	2 - MOMENT k % P	2 - MOMENT L $\bar{d}=\frac{\sum(L_s-L_c)}{n}$	2 - MOMENT L % P
0.10 vs. Control	23	1.15	72.8	-0.84	84.0	0.00226	65.9	-0.87	83.5
1.0 vs. Control	37	-0.80	51.5	-1.96	22.5	0.00916	21.4	-2.58	11.3
10.0 vs. Control	23	-1.88	38.5	-4.54	13.0	-0.01417	5.4	2.37	54.1
1.0 vs. 0.1	23	-2.57	20.5	-0.31	88.5	-0.00557	4.5	-0.22	91.5
10.0 vs. 1.0	23	-0.46	72.5	-3.39	1.3	-0.01087	15.5	3.45	31.5
10.0 vs. 0.1	23	-3.04	9.2	-3.69	1.1	-0.01643	0.8	3.24	40.5

radioactivity. In comparing the control values with those of the radioactive samples, the hypothesis that there is no difference between them is quite strongly supported in all instances except for the k value at the 10.0 mc/l level. Even in this instance the probability is above the 5 per cent significance level which is commonly adopted in biological experimentation. It is to be noted, however, that very low probabilities are obtained when comparing the k values for 0.1 and 10.0 mc/l levels and the seven day BOD for the 10.0 level with the 0.1 and 1.0 levels.

The results of the analyses of variance applied to several of the parameters are given in the following tabulation: The F ratio in each case is the ratio of the variance between columns to the residual and P is the probability of obtaining by chance alone a value of F equal to or greater than actually observed.

TABLE 31

RESULTS OF ANALYSIS OF VARIANCE OF BOD PARAMETERS WITH P^{32} (Runs 17-39)

PARAMETER	CONTROL	0.1 mc/l	1.0 mc/l	10.0 mc/l	F Ratio	% P
Aver. 7 day BOD	120.3	119.4	119.1	115.7	1.268	29.3
Aver. 2 moment k	0.172	0.174	0.168	0.157	3.58	2.7

Applied to the 7 day BOD values the analysis provides no justification for rejecting the hypothesis that there was no difference between the values at the various levels of activity. However, applied to the k values the analysis indicates that the values in the columns should vary as much as was observed only 2.7 per cent of the time if the null hypothesis were true. This suggests that there is a reasonable justification for rejecting the hypothesis and that there was a real justification for classifying the values according to the levels of radioactivity. It can be seen by inspection that the mean values of k for the control, 0.1 mc/l level and the 1.0 mc/l level are quite close to each other and that the low probability is due mostly to the relatively low value of k at the 10.0 mc/l level. This result, together with the low probabilities found by the "t" tests suggest that there is a real effect exerted by the P^{32} at the 10.0 mc/l level of activity. It is to be noted that the difference between either the 5 or the 7 day y values of the control and 10.0 mc/l samples are not great enough in magnitude to show any great statistical significance. However, the k values, which are functions of all seven y values, do show statistical significance since all of the average y values for the 10.0 mc/l level are consistently lower than those for the control.

The general conclusion reached by the results of the statistical analyses is that it is quite improbable that the divergence noted between the control and the 10.0 mc/l level on figure 11 could be accountable to chance alone. The difference is so small so as to be of no practical significance but the evidence suggests that it is real and would be maintained under continued experiments.

Supporting evidence that the reaction is beginning to be influenced at the 10.0 mc/l level is provided by the data on nitrification. Tables 11 and 12, which give the nitrite and nitrate concentrations on the seventh day of incubation, show very little difference between the control and the 0.1 and 1.0 mc/l levels but indicate a consistantly sharp reduction in both nitrite and nitrate concentration at the 10.0 mc/l level.

E. Effect of P^{32} on the Second Stage

The BOD values measured during the second stage with P^{32} are given in table 10. These values do not represent the total BOD exerted by the fresh sewage but were measured on diluted sewage samples which had been allowed to stand under aerobic conditions for 6 days and then re-aerated before bottling. They therefore represent the values of the BOD exerted after the sixth day. Although these are not total values they demonstrate how the onset of the second stage was delayed in the case of the 10.0 mc/l level. A rapid increase in the rate of oxygen utilization occurred between the 12th to 15th day in the case of the control samples and the 0.1 and 1.0 mc/l levels, whereas the 10.0 mc/l samples required several more days before any appreciable increase in rate occurred. These results provide strong support to the contention that the process of oxidation is affected by the presence of P^{32} at the 10.0 mc/l level of activity but is not appreciably effected at the lower levels.

The data on nitrification during the second stage is given in table 13. The values are extremely variable but do indicate the increased nitrification as the reaction proceeded. On the average there appears to have been a reduction in the production of nitrites and nitrates at the 10.0 mc/l level.

The results of bacterial population studies are shown graphically in figure 9. Since the results of plate counts made in this manner are bound to show wide variation, no great significance can be attached to these results. However, they indicate that the radioactivity did not exert any great effect on the bacterial growth.

F. Effect of I^{131} on the First Stage BOD

The results of the "t" test applied to the 5 and 7 day y values and the two moment k and L are given in table 32. It is seen that the differences which were observed in figures 12 and 13 between the average y values of the control and the radioactive samples are highly significant. Very low probabilities exist that these differences could have been due to chance alone. The relatively high values found for the probability when comparing k and L of the control with the 0.01 and the 10.0 mc/l levels are due to the greater variability of these parameters and the relatively low number of runs at these levels. The results taken as a whole leave little doubt that the presence of the I^{131} had considerable effect on the reaction.

The statistical tests indicate that the differences noted between the results among the various activity levels themselves could easily have been due to chance alone. The only conclusion that can be reached from these results is that any real differences in the effects within the range of the activity level studied must be small. A wider range of activity levels might have shown much greater divergences.

The data on nitrification is too erratic to permit rigid interpretation. In general, however, the production of nitrites and nitrates during the first seven days appears to have been lower on the average for the radioactive samples than for the control and there appears

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TABLE 32

RESULTS OF "t" TEST ON FIRST STAGE BOD PARAMETERS

OBTAINED WITH I^{131}

RADIOACTIVITY IN mc/l	NO. OF RUNS	5 - DAY BOD: $\bar{d} = \frac{\Sigma(y_s - y_c)}{n}$	5 - DAY BOD: % P	7 - DAY BOD: $\bar{d} = \frac{\Sigma(y_s - y_c)}{n}$	7 - DAY BOD: % P	2 - MOMENT k: $\bar{d} = \frac{\Sigma(k_s - k_c)}{n}$	2 - MOMENT k: % P	2 - MOMENT L: $\bar{d} = \frac{\Sigma(L_s - L_c)}{n}$	2 - MOMENT L: % P
Control vs. 0.01	10	-10.21	0.90	-14.98	0.20	0.0097	20.5	-13.3	15.0
Control vs. 0.1	16	- 7.44	0.16	-11.44	0.26	0.0131	6.8	-17.2	0.03
Control vs. 1.0	18	- 7.41	0.02	-11.71	0.04	0.0221	1.7	-17.5	0.04
Control vs. 10.0	5	- 9.72	1.92	-16.46	0.03	0.0140	51.5	-23.7	8.0
0.01 vs. 1.0	10	3.20	13.8	2.8	23.5	0.0066	17.5	- 3.42	57.0
1.0 vs. 10.0	5	- 0.66	59.0	- 2.40	34.5	0.0018	85.5	- 3.20	50.0
0.1 vs. 10.0	5	0.49	96.0	- 3.16	18.5	0.0054	40.5	- 3.36	42.5

to have been little difference between the results at the various levels of activity.

The average bacterial densities observed during the first six days, as shown on figure 10, do not show any great divergences.

G. Effect of I^{131} on the Second Stage BOD

The BOD values measured during the second stage with I^{131} are given in table 22. As previously explained for the second stage measurements made with P^{32} these values represent the BOD exerted after the sixth day. The values show that the increase in the rate of oxygen utilization which characterizes the beginning of the second stage occurred earlier for the control runs than for any of the radioactive samples. Among the different levels of radioactivity the observed differences are not great enough to show any statistically significant divergences.

V. CONCLUSIONS

A. Effect of P^{32} on the Biochemical Oxidation of Domestic Sewage

The presence of radioactive phosphorus, P^{32}, with initial levels of activity of 0.10 and 1.0 millicuries per liter does not exert a measurable effect on the course of the biochemical oxidation of fresh domestic sewage. The presence of P^{32} with initial activity of 10.0 millicuries per liter appears to reduce the rate of oxygen utilization to an extent which is of little practical significance.

B. Effect of I^{131} on the Biochemical Oxidation of Domestic Sewage

The presence of I^{131} with initial activities ranging from 0.01 millicuries per liter to 10.0 millicuries per liter appears to produce a decrease in the rate of oxygen utilization which results in a reduction in the total oxygen demand of about ten per cent by the seventh day. There appears to be very little divergence between the effects produced at the different activity levels within the range studied.

APPENDIX

TABLE 33

SUCCESSIVE VALUES OF **k** BY THE TWO MOMENT METHOD

FOR CONTROL RUNS (P^{32})

RUN NO.	Number of days used in the calculation 2	3	4	5	6	7
2	0.430	0.275	0.231	0.225	0.212	0.217
4	0.413	0.273	0.155	0.146	0.152	0.150
5	0.388	0.425	0.187	0.176	0.137	0.117
6	0.183	0.292	0.244	0.224	0.206	0.201
8	0.316	0.291	0.224	0.224	0.206	0.201
9	0.425	0.200	0.183	0.156	0.150	0.157
10	0.238	0.145	0.141	0.157	0.158	0.158
12	0.207	0.140	0.148	0.163	0.170	0.166
13	0.342	0.185	0.131	0.148	0.148	0.155
14	0.348	0.407	0.174	0.169	0.159	0.159
15	0.232	0.119	0.132	0.137	0.145	0.145
16	0.452	0.162	0.216	0.203	0.189	0.175
17	0.425	0.205	0.180	0.167	0.167	0.157
19	0.332	0.168	0.163	0.151	0.157	0.144
20	0.295	0.100	0.082	0.126	0.141	0.134
21	0.345	0.187	0.140	0.137	0.135	0.131
22	0.273	0.173	0.195	0.193	0.181	0.187
23	0.507	0.389	0.207	0.178	0.174	0.163
24	0.368	0.152	0.135	0.132	0.132	0.136
25	0.340	0.167	0.162	0.159	0.154	0.140
26	0.435	0.173	0.155	0.154	0.159	0.163
27	0.482	0.316	0.175	0.180	0.167	0.163
28	0.317	0.140	0.158	0.162	0.171	0.164
29	0.130	0.134	0.141	0.147	0.142	0.148
30	0.215	0.190	0.112	0.181	0.130	0.111
31	0.279	0.203	0.178	0.192	0.188	0.176
32	0.310	0.116	0.137	0.133	0.139	0.152
33	0.163	0.140	0.180	0.183	0.171	0.186
34	0.327	0.237	0.214	0.213	0.223	0.233
35	0.190	0.259	0.280	0.260	0.250	0.234
37	0.238	0.260	0.250	0.261	0.251	0.223
38	0.153	0.120	0.162	0.194	0.189	0.192
39	0.123	0.117	0.185	0.180	0.174	0.175
AVERAGE	0.310	0.208	0.174	0.175	0.170	0.166

TABLE 34

SUCCESSIVE VALUES OF L BY THE TWO MOMENT METHOD

FOR CONTROL RUNS P^{32}

RUN NO.	Number of days used in the calculation 2	3	4	5	6	7
2	55.7	70.2	77.8	78.6	81.1	80.2
4	70.6	107.4	127.0	132.0	129.0	129.8
5	19.6	18.7	29.0	30.0	35.0	38.5
6	75.2	54.9	60.8	63.5	66.4	67.1
8	81.4	85.7	99.5	112.8	115.1	114.2
9	58.6	92.5	98.0	108.1	111.0	108.4
10	75.9	109.1	111.3	103.4	103.3	103.3
12	141.2	189.7	182.9	171.0	167.4	169.1
13	74.6	111.0	141.6	130.3	130.3	127.1
14	94.1	101.5	147.7	150.0	156.0	156.1
15	90.7	149.5	138.8	134.7	130.2	130.3
16	80.9	108.9	122.8	126.7	131.9	137.1
17	70.4	108.9	118.7	124.1	124.5	129.0
19	91.6	144.5	147.2	154.8	151.2	158.7
20	32.3	73.9	82.6	61.0	56.8	58.7
21	78.6	106.6	130.4	132.0	133.8	136.3
22	120.0	164.5	150.8	152.8	153.8	155.4
23	82.9	94.2	131.7	143.7	146.1	151.2
24	71.2	127.3	138.6	140.6	141.0	139.0
25	65.1	104.8	106.4	107.7	110.1	116.4
26	80.9	143.3	154.3	155.2	152.3	150.3
27	65.7	81.5	115.8	110.4	118.8	120.5
28	85.3	150.6	137.6	135.4	131.7	134.5
29	126.2	145.8	139.8	135.8	138.9	135.4
30	98.0	134.8	160.0	124.3	144.2	159.0
31	100.8	125.8	137.0	131.0	132.6	137.2
32	70.1	142.1	125.1	127.8	124.4	118.1
33	116.0	137.0	114.6	113.5	116.3	112.5
34	87.6	106.7	114.4	114.0	111.4	109.2
35	145.3	117.0	112.4	116.3	118.8	121.9
37	132.6	125.0	128.1	125.4	127.7	134.3
38	150.1	194.3	156.4	140.3	142.4	141.3
39	125.0	151.6	109.7	111.6	113.9	113.2
AVERAGE	88.3	117.6	122.7	121.2	122.6	124.0

TABLE 35

STUDENT'S "t" TEST FOR THE SIGNIFICANCE OF DIFFERENCES IN k VALUES
(Computed by Two Moment Method)
BETWEEN CONTROL AND RADIOACTIVE SAMPLES (0.1 mc/l of P^{32})

SAMPLE CALCULATION

RUN	k_c	k_s	$d = k_s - k_c$	$d^2 = (k_s - k_c)^2$
17	.157	.145	-0.012	0.000144
18	.132	.149	0.017	0.000289
19	.144	.146	0.002	0.000004
20	.134	.168	0.034	0.001156
21	.131	.159	0.028	0.000784
22	.187	.156	-0.031	0.000961
23	.163	.180	0.017	0.000289
24	.136	.125	-0.011	0.000121
25	.140	.154	0.014	0.000196
26	.163	.180	0.017	0.000289
27	.163	.135	-0.028	0.000784
28	.164	.177	0.013	0.000169
29	.148	.173	0.025	0.000625
30	.111	.124	0.013	0.000169
31	.176	.181	0.005	0.000025
32	.152	.161	0.009	0.000081
33	.186	.192	0.006	0.000036
34	.233	.206	-0.027	0.000729
35	.234	.257	0.023	0.000529
36	.299	.243	-0.056	0.003136
37	.223	.251	0.028	0.000784
38	.192	.181	-0.011	0.000121
39	.175	.152	-0.023	0.000529
			$\Sigma d = 0.052$	$\Sigma d^2 = 0.011950$

$n = 23$

$\bar{d} = 0.002260869$

$(\Sigma d)^2 = 0.002704$

$$\sqrt{\frac{(\Sigma d^2) - \frac{(\Sigma d)^2}{n}}{n\,(n-1)}} = 0.0048356$$

$$t = \frac{\bar{d} - \bar{d}'}{0.0048356} = 0.46753$$

Degrees of Freedom = 22 Probablilty, P, = 0.65912, say 65.9%

This is based on the hypothesis that the difference between reaction velocity constants is zero. A difference as great or greater than that observed between the calculated k-values would occur 65.9% of time due to chance factors alone if the hypothesis is true.

TABLE 36

SAMPLE CALCULATION

ANALYSIS OF VARIANCE

First Stage Reaction Velocity Constants with P^{32}

RUN	CONTROL	Initial Radioactivity-Millicuries per Liter 0.1	1.0	10.0
17	.157	.145	.158	.161
18	.132	.149	.122	.128
19	.144	.146	.138	.153
20	.134	.168	.149	.147
21	.131	.159	.168	.053
22	.187	.156	.165	.187
23	.163	.180	.173	.177
24	.136	.125	.128	.142
25	.140	.154	.136	.168
26	.163	.180	.177	.160
27	.163	.135	.143	.171
28	.164	.177	.170	.108
29	.148	.173	.170	.087
30	.111	.124	.131	.101
31	.176	.181	.168	.164
32	.152	.161	.138	.123
33	.186	.192	.195	.216
34	.233	.206	.183	.164
35	.234	.257	.246	.220
36	.299	.243	.223	.227
37	.233	.251	.241	.242
38	.192	.181	.197	.188
39	.175	.152	.148	.130
$\bar{k}$	0.172	0.174	0.168	0.157

		Variation or Sum of Squares	Degrees of Freedom	Variance or Mean Square
Among Columns (Sewage Types):	$\frac{n_r \cdot \sum(\bar{k}_c - \bar{\bar{k}})^2}{\text{no.of cols} - 1}$	0.378	3	0.126000
Among Rows (Runs):	$\frac{n_c \cdot \sum(\bar{k}_r - \bar{\bar{k}})^2}{n - \text{no.of cols.}}$	11.945	22	0.542954
Residual:		2.322	66	0.035182
Total:	$\frac{\sum(k - \bar{k})^2}{n - 1}$	14.645	91	

F, testing difference between sewage types: $F = \frac{0.12600}{0.03518} \left\{ \frac{df_1 = 3}{df_2 = 66} \right\} = 3.5813$, P= 0.02725

F, testing difference between runs: $F = \frac{0.54295}{0.3518} \left\{ \frac{df_1 = 22}{df_2 = 66} \right\} = 15.433$, P < 0.001

TABLE 37

VALUES OF DECAY CONSTANT, λ *WITH P^{32}

RUN	ISOTOPE DILUTION	Activity of Sewage Dilution 0.1 mc/l	1.0 mc/l	10.0 mc/l
2	.028470			
3	.025872		.020093	
4	.024538			
5	.024369		.024380	
8	.018681		.018496	
9	.021254		.020669	
10	.020546		.021061	
11	.022465		.020963	
12	.020696		.020792	
13	.022395		.023223	
15	.021081		.022230	
16	.024647		.021166	
19	.023580	.021721	.022502	.021986
20	.020706	.022278	.022093	.019395
21	.033059	.020284	.018394	.018525
22	.055428	.022672	.023779	.024070
23	.027797	.019842	.020411	.020889
25		.021833	.022513	.026670
26		.021233	.024624	.032264
27		.022861	.024368	.035098
28	.025773	.022486	.021709	.034606
29	.030064	.023458	.022159	.033494
30	.033153	.021918	.020960	.057019
31		.019338	.019248	.046156
32		.023299	.024880	.058955
AVERAGE	0.026229	0.021786	0.021770	0.033100

* λ = constant in equation $A_t = A_o \cdot 10^{-\lambda t}$ in which

A_o = initial level of radioactivity

A_t = activity level at end of t days

Generally accepted value of λ = 0.02105

TABLE 38

VALUES OF DECAY CONSTANT λ^* WITH I^{131}

Isotope Dilution		Radioactive Sewage – 1.0 mc/l	
RUN	λ	RUN	λ
4	.031912	1	.042524
5	.042501	2	.044993
6	.036607	4	.034101
7	.038379	5	.065379
9	.046901	9	.037290
10	.039239		
11	.035736	11	.041030
12	.035033	12	.045672
13	.036804	13	.039058
14	.037685	14	.033148
15	.038437	15	.038571
16	.031735	16	.052206
17	.044953	17	.037973
18	.035629	18	.038318
19	.030946	19	.039354
20	.039799	20	.039279
AVERAGE =	.037644		.041926

* See note on Table 37

Generally accepted value of λ = 0.03763

LIST OF TABLES

LIST OF REFERENCES

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