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UNITED STATES ATOMIC ENERGY COMMISSION

BIOCHEMICAL OXYGEN DEMANDS OF RADIOACTIVE SEWAGE

(Progress Report)

by

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March 1950

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Progress Report
Waste Disposal Project

BIOCHEMICAL OXYGEN DEMANDS OF RADIOACTIVE SEWAGE

Progress Report

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Rolf Eliassen
and
Werner N. Grune

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- ABSTRACT -

In this report the first findings of the effect of radioactvity on sewage are reported. This far, no real significance can as yet be arrived at, pending further investigations and additional laboratory runs.

Under investigations, and reported herin, are the reaction rate constant of the Biochemical Oxygen Demand of sewages, the dilution water used for this purpose, nitrification, and both first and second stage observations, are all compared to the possible effect that radioactivity might have on ~~these~~ sewage when discharged as a waste product. End

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I. INTRODUCTION

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The Sanitary Engineering Research Laboratory of the College of Engineering at New York University has been engaged in radioactive waste disposal research for over eighteen months.

The problem is to study the effect of radioactive materials which find their way into sewers, sewerage systems, and treatment plants. The criteria selected to observe and scrutinize these effects are the reaction velocity constant (k) of the biochemical oxidation reaction of sewage and wastes as well as the ultimate first stage B.O.D. value, (L).

The first of these two criteria was selected to observe the effects on the chemical kinetics of the oxygenation system, which is highly useful in characterizing a particular sewage and the course it takes while being stabilized. The second of these parameters, the ultimate first stage B.O.D., commonly referred to as the L_0 value, is a useful figure to measure the overall pollutional strength of a sewage or trade waste. In studying the effects of radioactivity on sewage the evaluation of these two parameters yields highly pertinent information on how sewages will react when they become radioactive due to the discharge of isotopic wastes.

Reports NYU-2, 3, and 4 have depicted progress which has been made in studying the domestic sewage (Bronx sewage) used as the substrate in these investigations. These reports have covered the topics of radioactive counting, a completely new and different tool to the sanitary engineer; the composition and characteristics of the domestic sewage; and the statistical approach in evaluating the several variables influencing the reaction rate constant k. The basis was therefore established for work to proceed on the addition of radioisotopes to domestic sewage. This report will deal with the observations made from May 1949 through February 1950 on the effect of radiophosphorus (P^{32}) on Bronx sewage, and serve as a preliminary report until further data can be collected and final conclusions reached.

II. TECHNIQUES AND PROCEDURES

The procedure, originally outlined in detail in report NYU-3, has been further developed and more highly adapted and specialized to the specific needs of a dissolved oxygen determination by the modified Winkler Method under radioactive conditions. The routine test for dissolved oxygen in water, sewage, and trade wastes is one familiar to every sanitary chemist and engineer. The unusual situation of having to perform this analytical work under radiological conditions presented great difficulties for a protracted length of time. A very detailed description of how this problem was finally solved (not only for P^{32} but also for I^{131}, soon to be investigated) can be found in report NYU-5.

In this report only those parts of the procedure pertinent and directly affecting the solution of the problem will be treated.

The sewage, as previously reported, is sampled from a manhole on West Burnside Avenue, The Bronx, New York, directly opposite the Lewis V. Carpenter Sanitary Engineering Research Laboratory. The contributory population is purely domestic which makes it excellent for sampling from the standpoint of sewage characteristics. However, the strength of the sewage is rather low, primarily due to the high water consumption experienced in this part of the city and the freshness of the sewage, with little comminution having taken place prior to sampling. The steep slopes of the neighboring streets leads to high sewage velocities, with corresponding turbulence and aeration.

Records of the Department of Public Works of the City of New York show that stronger domestic sewage samples can be obtained in the

Jamaica and Coney Island areas. A stronger sewage will exert a higher Biochemical Oxygen Demand (B.O.D.), which may result in a more characteristic unimolecular reaction. Under those conditions the k values obtained might possibly be more significant and easier to compare when the effect of radioactivity is studied.

The present sampling point was chosen initially and continued in use because it presented several distinct advantages:

1) Proximity of manhole to laboratory.
2) A minimum elapse of time from time of sampling until B.O.D. test bottles are placed into incubator. Very little interference with the lag period, highly important in the evaluation of k values.
3) Almost certain that no industrial wastes and toxic materials are ever present in this sewage.
4) The sewage is always fresh. No decomposition of any significance has taken place.

The main reason for not using Coney Island or Jamaica sewage as the sewage substrate for experimental purposes at this laboratory is because some value might be lost in transporting samples for protracted periods. Eventually it is planned to make a few experimental runs with Jamaica or Coney Island sewage as substrate.

It is a well known fact that sewage composition varies throughout the day. To minimize this variation, the sampling time of 9:00 a.m. was previously established. (See NYU-3, page 3.) This permits a reasonably homogeneous sample to be obtained as far as sewage character and strength are concerned.

Report NYU-3 stated that Tuesday was to be established as the sampling day for the sake of uniformity of sewage character. It was definitely proven that the day of the week has a direct effect on the character of The Bronx sewage (see page , Report NYU-4). As can be seen in Table I "Table of k Values and Other Pertinent Information" page 16, work was started with Radioactive Run I and Run II on Tuesday's sewage sample as the substrate. It was soon learned that definite delivery of isotope at this laboratory for Tuesday morning could not be maintained. The isotope is always shipped from Oak Ridge on Monday but weather conditions, delivery connections, etc. have caused incalculable delays. Table I shows that Runs No. III and IV had to be made on Thursday and Wednesday respectively. With Run No. XII Tuesday was definitely abandoned as the sampling day and Wednesday established after shipping difficulties and air traffic conditions were ironed out. Thus Runs XII through XX were all made with samples taken Wednesday mornings at 9:00 a.m. This timing will be adhered to in the future.

Immediately after collection of the sample, the sewage is filtered through nonabsorbent cotton to remove large suspended solids, yielding a filtrate which simulates primary settled sewage as closely as possible for the experimental runs. Almost all municipal sewage treatment plants employ primary settling as the initial unit operation in the processing of sewage. In the primary settling tanks the larger suspended solids are removed in a period of one to two hours. Where further treatment is necessary, the sewage may then be applied to a secondary unit operation, usually biochemical and biological in nature, such as trickling filters and activated sludge tanks. The purpose of cotton filtering sewage for these experiments is two-fold: a) to simulate plant conditions, and b) to remove suspended solids which could easily absorb and assimilate radioactivity (P^{32}) and thus alter the observed effects.

In order to reduce the lag period (see page , NYU-4) the greater proficiency of laboratory procedures and techniques have made it possible to have all B.O.D. bottles incubated within three hours after sampling. Therefore the lag has been reduced to a minimum.

The temperature of the raw sample, just after collection, is recorded in Table I starting with RunXVII. This temperature, actually is the temperature of the sewer and its contents. Since temperature differences may affect bacterial populations, any unusual effects in the sewage might be attributed to different bacteria as well as the addition of radiophosphorus (P^{32}), the latter being in part the inhibitor or accelerator of the biochemical oxygen demand reaction understudy. It was upon reflection of some of the earlier data obtained and the variability of k values that this additional reading was deemed very much worth while.

The procedure for the preparation of the dilution water has also been improved. Five 18 liter carboys are now filled simultaneously with distilled H_2O and immediately aerated with compressed air. An aeration period of two full days will bring the dissolved oxygen content up to 95-99% saturation values. The contents of these five carboys are then poured into a 30 gallon Stoneware Crock. This large volume of dilution water is needed for a run which includes three levels of activity such as Runs No. XVII to XX inclusive. It is of paramount importance to have all dilution water age in the identical manner and for the same length of time. In this fashion all adjustments of dissolved oxygen content between the several carboy contents can be achieved. "Layering" of dissolved oxygen is at a minimum and is tested for in the initial dissolved oxygen determinations made on the day of the run. Thus, any differences in dissolved oxygen, if still present after this careful treatment, are recorded as part of the data.

The initial 18 liter carboys, as well as the 30 gallon Stoneware Crock, are carefully washed with distilled water afterwards. No detergents are used since foreign material might be added rather than cleaning effected, since the 18 liter carboys never receive any inert material knowingly. After the sewage dilution, which was prepared in these vessels, has been used up to fill the B.O.D. bottles, the inside of the 30 gallon crock is initially washed down vigorously on the inside with a hose. Then the aforementioned distilled water wash is applied. During all other times cotton plugs are maintained on the 18 liter carboys and the 30 gallon crock has its cover in place, except when certain manipulations are necessary, at which time these aseptic devices are removed for as brief a period as possible.

In improving the dilution water technique and increasing the period of aging from overnight to five days and even a week, increasingly reliable dissolved oxygen data on the dilution water have been collected. (See Table XII "Dilution Water Data".)

Air microbes, B. Sublitis and yeasts may be responsible for the depletion of the dissolved oxygen in dilution water. This slight "B.O.D. exertion" over a seven-day testing period of incubated B.O.D. samples does complicate the computations and mask possible significance. It is thus of utmost importance to have at disposal of the worker a dilution water whose dissolved oxygen demand is infinitesimal. In the early stages of this project and until relatively recently sufficient carboys and personnel were not available to carry out this procedure.

Considerable attention has been given to the exact procedure used for the addition of sewage. This step is in effect another sampling procedure. Therefore extreme care must be exercised to turn out representative B.O.D. bottles, all with a homogeneous sewage population, or as nearly so, as can be achieved by the methods available. For these reasons the thirty gallon stoneware crock was purchased, so that one single addition of the sewage could take place. For a three-level concentration run, such as Runs XVII through XX inclusive, 90 liters (or 23 gallons) of distilled water must be made up initially. As previously mentioned after aeration this total quantity of water ages in the stoneware crock. The morning of the run the nutrient salts (Theriault-Nichols Dilution Water Formula) are added and well mixed just before the "cold" dilution blanks are siphoned off. In the next step the three "hot" concentration dilution water volumes are taken off by siphonage into 18 liter carboys, each volume being spiked to the specific level of activity with radiophosphorus in the "radioactive" laboratory. As the next stage in these operations, the sewage addition is made to the B.O.D. dilution water which is the only material remaining in the thirty gallon crock. Usually a 4% dilution is used in these experiments, having previously been established as the most significant dilution, (see Report NYU-3, page 50, "Summary and Conclusions"). Ordinarily this requires the addition of approximately 2¼ liters of settled sewage. The reason for this somewhat problematical and indefinite statement as to exact quantity is due to the variability of weather and consequent sewage flow dilution resulting. After a rain or snow spell the sewage will be more dilute due to runoff when sampled at 9:00 a.m. on Wednesday. Therefore a greater sewage dilution must be resorted to in order that variables of this kind may be taken into account and reasonably consistent results may be obtained in the laboratory.

After the addition of sewage to the B.O.D. dilution water remaining in the stoneware crock, one 18 liter carboy is siphoned off for "cold" B.O.D. bottle filling and a further set of three carboys, 18 liters each, is siphoned out and moved into the radioactive laboratory, where radiophosphorus is added as the final stage before filling B.O.D. bottles. In this manner, the most uniform distribution of sewage matter and organisms as possible is made to all the radioactive and non-radioactive sewage dilutions for B.O.D. determinations. This is of paramount importance.

The addition of radioactive material has been well standardized by thorough practice. After the isotope, as received from Oak Ridge, has been unpacked it is immediately placed under the air-evacuated hood behind proper shielding. In the earlier runs (Run I to Run XVI inclusive) when only 30 to 40 mc of radiophosphorus (P^{32}) were processed, $\frac{1}{4}$" Plexiglass or Lucite shielding was sufficient. The energy of P^{32} is 1.69 Mev from beta-radiation. However, with the advent of three-level concentration runs, such as Runs XVII through XX, a total quantity of from 270 mc to 300 mc have been processed. When these intensities of radioactivity are handled, it is found that secondary radiation, Brehmstrahlung, or K-capture electron energy conversion, shows up as Gamma-radiation, and under these circumstances $\frac{1}{4}$" Plexiglass no longer will give sufficient protection. For this reason 1/8" lead shielding has been in use for these "high activity" operations.

The isotopic material ($H_3P^*O_4$) is pipetted out of the original glass bottle by remote control (see Report NYU-5, page 22) and mixed with some of the dilution water or sewage dilution substrate in a heavy glass 500 cc Erlenmeyer flask. The total contents are then emptied into the particular 18 liter carboy in use for filling B.O.D. bottles. Stirring within the 18 liter carboy is then practiced to insure an even distribution of the isotope among its contents. In pipetting the original material, care is taken not to lose activity by adsorption to the glass of the pipet. Between uses the pipets are stored in a mild HCl solution. When the isotope must be pipetted the pipet is usually filled once with radioactive H_3PO_4 and then released again. A second filling of the pipet will actually be used to deliver the required amount.

The exact dosing amounts are calculated as soon as the Oak Ridge Packing List is received. The concentration in mc/ml is then corrected for decay. Since the half-life of radiophosphorus (P^{32}) is 14.3 days and the isotope is generally processed at this laboratory about fifty-two hours after the Oak Ridge National Laboratory assay, a decay correction of 90.5% must be undertaken. The calculation of the various dosages required for the three different levels of radioactive concentration, 0.1 mc/l, 1.0 mc/l, and 10.0 mc/l, for dilution water and sewage dilution each become simply a routine matter after that.

As noted, the chemical form of the isotope is H_3PO_4. Considerable correspondence, to determine whether the carrier is H_3PO_4, as originally ascertained, or HCl as calculated from the assay of the isotope, finally proved to be H_3PO_4. A small amount of HCl is added to prevent loss of activity during shipment to the glass walls of the container by reduction of the pH and also to prevent after-precipitation of the isotope and thus form a cloudy solution. However, it took a great deal of investigating to finally be absolutely certain of the chemical form of the isotope. The reason for the importance of knowing the exact chemical form of isotope added is that the same or equivalent chemical of the carrier must be added to the control, which is the non-radioactive sewage or "cold sewage". It is known that a trace amount of phosphate, when leaching into a well, can raise the bacterial count many fold, phosphates being excellent bacterial foods. Other chemicals have similar stimulating or adverse effects in trace quantities. Since the work of this project is devoted to the determination of the effect of radiophosphorus (P^{32}) addition, the carrier must be added to the control, so that the radioactive sewage differs only by its content of P^{32} alone. As will be seen in Table I, various changes in the mode of addition of control material took place. Runs V, VI, VII, VIII, and XX were conducted in the way which is now definitely considered correct and standard. During the interim period other modes of addition had to be practiced as the information gathered about the chemistry of the isotope and carrier varied. In the future H_3PO_4 will be added according to the specific activity to the control, i.e. the mg of P^{31} per mc of isotope added. (Usually this value is .025 mg P^{31}/mc.)

The matter of temperature of incubation was discussed and the constancy of temperature stressed (see Report NYU-3, page 20, "Temperature Effects"). Difficulty in maintaining a constant incubation temperature of 20°C was encountered in Runs I, II, and III (see Table I, page 16) for several reasons:

1) The "cold" and "hot" sewage were incubated in two different incubators so that a small variation in one refrigerator would upset the complete run. Neither incubator was large enough for all of the B.O.D. bottles necessary for one run.

2) The refrigerators used were of different makes, different precision, and thus very difficult to set exactly alike.

3) One of the incubators was greatly affected when the B.O.D. bottles were initially placed into it during the first day of the run. Evaporation from the water seal well of the bottles, with resulting condensation and cooling effects on the incubation temperature, resulted in adjusting the incubator <u>after</u> the bottles were started to incubate. To regulate the incubator before the run, which always was practiced, became useless and obsolete therefore.

This untenable situation was finally remedied by the purchase and installation of a large walk-in type refrigerator of sufficient capacity to handle all "cold" and "hot" bottles simultaneously. Thus, should there be any drops or changes in temperature, both experimental and control media would still be subjected to identical temperatures. Some adjustment of the data may be made under those circumstances, if necessary, but when the two types of runs are each subjected to different temperatures, no allowances and adjustments are possible. Therefore, this problem has been solved by the installation of one large incubator.

Since the beginning of comparative radioactive and non-radioactive experiments, the work has been separated according to that classification. In order to minimize radiation hazards and to preclude any irradiation of the "cold" control sewage, the latter run is completed in a "cold" laboratory. Only during incubation are the two sets of experimental B.O.D. bottles together in one refrigerator, which cannot be helped if temperatures are to be identical. However, there exists sufficient shielding between the two sets of B.O.D. bottles that no irradiation of "cold" sewage during incubation occurs.

The actual dissolved oxygen test procedure has been continued in exactly the same manner as reported previously (see Report NYU-3, page 5) and standardized (see Report NYU-5, page 26). The time sequences and the handling techniques have proven themselves and can be considered as the best available for our purposes.

The length of the experimental run was found to be most significant if seven-day data were observed, (see Report NYU-4, page), to obtain the most reproducible k values for the first stage of the B.O.D. reaction and for consequent statistical manipulations. Table I shows that most runs were extended for seven days and some for even fifteen and twenty days. One complete run, Run No. XI, was entirely devoted to the second stage of the biochemical oxygen demand.

The sodium thiosulfate, used for titration of dissolved oxygen, is standardized and checked for every run since it decomposes with light and time. For this reason it is kept in dark bottles thus leading to very little change. For the sake of accuracy, the chemical is periodically checked.

The manner of decontamination B.O.D. bottles, pipets, and other glassware has been somewhat altered. The previous method of soaking all glassware in a large soapstone basin in a weak H_3PO_4 solution has been discarded. It was found that the whole bath of H_3PO_4 became active and with subsequent evaporation exposed a radiation hazard to the workers in the laboratory, even though the basin was ordinarily kept covered. In addition, the large double-sink basin built up activity which with time could become dangerous. The numbers painted and baked on the B.O.D. bottles were also leached by this continuous soaking process. The changeover was made for these several reasons.

The method now adopted is much simpler and more effective. First of all, the decontaminant is now Na_2HPO_4 which is cheaper and has a pH much closer to neutral than the acid. Secondly, no large basin is provided for soaking. Each bottle is filled from a carboy of Na_2HPO_4 and left standing until sufficient exchange with radiophosphorus (P^{32}) has taken place. The bottle is given a clean "bill of health" after the monitoring Geiger-Mueller probe registers less than 0.15 mr/hr of activity rate ½" away from the top and the outsides of the bottle, the latter being generally less active to start with. Further savings have been effected by dumping the Na_2HPO_4 solution from one set of B.O.D. bottles into the next set of bottles, after the cooling period. This period has generally been found to be from seven to eight days depending primarily on how long the interior of the bottle was exposed to radiophosphorus (P^{32}) and the concentration level it contained.

Other glassware is decontaminated in similar fashion, including the 18 liter carboys used for the make-up of the B.O.D. run.

Before and after the Na_2HPO_4 treatment all bottles are thoroughly washed by inversion over a stand with water pressure jets supplying an intense tap water rinse. The latter has been found to be extremely effective, both to remove initial radioactivity after the contents have been titrated, and also after the Na_2HPO_4 soak.

III. RESULTS

Since April 1949 twenty laboratory runs have been made comparing radioactive with non-radioactive sewage. A summary of the results of these runs is presented in Table I (see page 16). Considerable time is expended in the preparation, actual operation and manipulation for each run. In the beginning of these radioactive experiments only one experimental run could be handled per month. Physical limitations such as incubation space, number of B.O.D. bottles available, laboratory space adapted to the use of radioactive tracer work and the number of air-evacuated hoods placed spacial and time delays on these experiments. Originally the staff on this project consisted of only one full time and one part time research worker.

A number of factors have contributed to speeding up the work and greatly increasing the number of runs performed per month. Among these are the following: thorough familiarity with the techniques involved; greatly improved equipment especially adapted to these experiments, including complete housing in an air-evacuation system; streamlined manual operations accompanied with improved shielding and radiation hazard curtailment; much larger incubation space and better temperature control; additional numbers of B.O.D. bottles; and a larger research staff. Above this, since January 18, 1950 three levels of activity of radiophosphorus (P^{32}) are investigated simultaneously. Instead of just a 1.0 mc/l concentration in the waste, the additional concentrations of 0.1 mc/l and 10.0 mc/l are simultaneously processed.

Thus, the above improvements have led from the initial state of one radioactive run per month to the point where the laboratory staff

TABLE I "Table of k Values and other Pertinent Information".

TABLE OF k VALUES

COMPUTED BY METHOD OF MOMENTS

RUN NO.	DATE 1949 1950	k				SAMPLE DAY	% SEWG DLN.	SEWAGE D.O. PPM	ADDN. OF SEWAGE	P DLN BLKS	INCUB. TEMP. CONST.	CONTROL MATL ADDED	MODE OF ADDN	ACC TO CONCERN.	SEWAGE TEMP WHEN COLLEC. mc/1	DURATION OF RUN	TOTAL SOLIDS	CHLORIDES	HEAVY METALS	OTHERS	REMARKS
		COLD	RADIOACTIVE mc/1																		
			0.1	1.0	10.0																
I	4/19	.200		.250		Tues.	4%	7.5	Both	No	No	No	-	1.0	60°F	7 days	4200	3800	--	200 NVM	-
II	5/10	.217		.258		Tues.	5%	7.1	Single	No	No	No	-	1.0	78	15 "	1400	640	--	200 NVM	-
III	6/2	.319		.200		Thurs.	5%	6.5	Single	No	No	No	-	1.0	70	7 "	1900	120	Negative	0 NVM	-
IV	6/15	.151		.213		Wed.	4%	6.1	Single	No	Yes	No	-	1.0	74	7 "	750	625	50	3.5 A , 200 NVM	-
V	7/7	.117		.222		Thurs.	4%	0.55	Single	No	Yes	H_3PO_4	Specific Activity	1.0	80	7 "	850	250	20	0 NVM	-
VI	7/26	.201		.355		Tues.	4%	6.833	Single	No	Yes	H_3PO_4	"	1.0	81	7 "	400	210	20	0 NVM	-
VII	8/10	.10		-		Wed.	4%	3.65	Single	No	Yes	H_3PO_4	"	1.0	81	7 "		None	10	1700 NVM	-
VIII	9/29	.170		.192		Thurs.	4%	3.038	Single	Yes	Yes	H_3PO_4	"	1.0	-	15 "	200	1660	20	0 NVM	-
IX	10/19	.156		.314		Wed.	4%	6.20	Both	Yes	Yes	No	-	1.0	75	15 "	4300	6800	20	300 NVM	-
X	11/2	.158		.149		Wed.	4%	6.00	Both	Yes	Yes	No	-	1.0	-	15 "	1500	None	20	500 NVM	-
													According to Normality	1.0	70	20 "	550	150	20	200 NVM	Second Stage
XI	11/28					Mon.	2.5%	5.70	Both	Yes	Yes	H_3PO_4	"	1.0	65	7 "	None	600	20	None	-
XII	11/30	.166		.173		Wed.	4%	6.60	Single	Yes	Yes	H_3PO_4	"	1.0	65	7 "	1050	4300	20	200 NVM	-
XIII	12/7	.155		.157		Wed.	4%	6.85	Single	Yes	Yes	H_3PO_4	"	1.0	69	7 "	1300	660	20	None	-
XIV	12/14	.159		.171		Wed.	4%	7.50	Single	Yes	Yes	H_3PO_4	"	1.0	64	7 "	1900	1100	20	1200 NVM	-
XV	1/4	.145		.167		Wed.	4%	6.725	Single	Yes	Yes	HCl	"	1.0	61	7 "	800	800	20	0 NVM	-
XVI	1/11	.174		.200		Wed.	4%	6.75	Single	Yes	Yes	HCl	"	1.0	15°C	7 "	0	1400	20	0	-
XVII	1/18	.157	.145	.158	.161	Wed.	4%	7.10	Single	Yes	Yes	H_3PO_4	"	10.0	18°C	7 "	700	1520	20	200 NVM	-
XVIII	1/25	.133	.149	.122	.128	Wed.	4%	6.25	Single	Yes	Yes	HCl	"	1.0	18°C	7 "	0	2670	20	0	-
XIV	2/1	.144	.146	.138	.154	Wed.	4%	7.00	Single	Yes	Yes	HCl	Specific	1.0	13.5°C	7 "	3100	1300	20	0	-
XX	2/15	.134	.168	.149	.147	Wed.	5%	10.0375	Single	Yes	Yes	H_3PO_4	Activity								

NOTE: Temperatures of Sewage when recorded in degrees Fahrenheit as were recorded by Ward's Island Treatment Plant, N.Y.C.

These temperatures correlate very closely with those taken later by this laboratory (those marked by °C.

can turn out from two to four runs per month. Instead of only one concentration of radiophosphorus (P^{32}), three levels of activity are simultaneously investigated in each run. Therefore, the total research activity has been stepped up from six to twelve fold. It is believed necessary to carry on these investigations at this high rate of productivity in order to complete all P^{32} work, with a significant solution to the problem by the summer of 1950 so that radioiodine (I^{131}) investigations can get under way.

With respect to all biochemical oxygen demand work it must be reiterated at this point that it takes seven days of successive testing to establish one value of the reaction rate constant, k. With one sample of sewage and isotope, only a certain amount of investigation can be carried out. It must be realized that with one sample of sewage and one isotope it is physically impossible to make a multitude of simultaneous analyses, as would be desirable from the standpoint of statistical homogeniety.

Of the twenty runs which are shown in Table I, two of these runs cannot be considered directly applicable or useful for the purpose of this report. Run No. VII actually had depleted the dissolved oxygen after the second day; therefore, no significant results were obtained. Run No. XI was an investigation of the second stage of the Biochemical Oxygen Demand reaction, or the nitrification stage. The remaining eighteen runs are homogeneous insofar as they all test the first or carbonaceous oxidation stage.

It will be noticed that almost all k values for the radioactive sewage show a slightly elevated value. More specifically, there are fourteen out of these eighteen runs in which the k value is greater for the radioactive sewage, the difference ranging from .001 to 0.167 in excess of the k value for the ordinary sewage or control sample. The other four runs, Runs Nos. III, X, XVIII, and XIX exhibit a greater k value for the ordinary sewage than for the radioactive material. In order to test this data to determine whether the difference is statistically significant, and whether radiophosphorus exerts a definite influence on the stabilization rate of domestic sewage, a statistical analysis has been made of these eighteen runs. This analysis is presented in Table II on page 19.

Inspecting the data further it was felt that since not all runs could be made on a Wednesday sewage substrate, for reasons outlined before, a statistical analysis should also be made on the basis of Wednesday's sewage results only. See Table III, page 20, for these results.

A further division of the data was undertaken starting with Run No. XII. The reason for this segregation is that the data starting with Run XII represents the runs made under the most homogeneous conditions as far as the following variables are concerned: day of sewage sample; addition of sewage; dilution blanks incubated in parallel; constancy of incubation temperature; and also as far as visual homogeneity of the data goes. The analysis of results on Runs XII through XX are shown in Table IV, page 21.

Starting with the XVIIth Run, besides the regular 1.0 mc/l concentration of radiophosphorus (P^{32}) of the radioactive sewage, 0.1 and 10.0 mc/l concentrations were also studied. The results are analyzed by statistical analysis even though up to the present time there are relatively few observations to work with. See Table V, page 22, for these results.

TABLE II

ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} AND k_{HOT} FOR ALL RUNS. (1.0 mc/1 pfP^{32})

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.200	.250	+.050	.002500
.217	.258	+.041	.001681
.319	.200	-.119	.014161
.151	.213	+.062	.003844
.117	.222	+.105	.011025
.201	.355	+.154	.023716
.176	.192	+.016	.000256
.156	.314	+.158	.024964
.158	.149	-.009	.000081
.166	.173	+.007	.000049
.155	.157	+.002	.000004
.159	.171	+.012	.000144
.145	.167	+.022	.000484
.174	.200	+.026	.000676
.157	.158	+.001	.000001
.133	.122	-.011	.000121
.144	.138	-.006	.000036
.134	.149	+.015	.000225
		$\sum d = .526$	$\sum(d^2) = .083968$

$$\bar{d} = .02922222$$

$$(\Sigma d)^2 = .276676$$

$$(\Sigma d)^2/n = .0153708888$$

$$\sigma' d \text{ est.} = \sqrt{\frac{\Sigma(d^2) - \frac{(\Sigma d)^2}{n}}{n-1}} = \sqrt{\frac{.083968 - .0153708}{17}} = \sqrt{\frac{.068597}{17}}$$

$$= \sqrt{.00403511764} = .063525$$

$$\sigma \bar{d} = \frac{\sigma' d \text{ est}}{\sqrt{n}} = \frac{.063525}{4.242641} = .01497298$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma \bar{d}} = \frac{.02922222}{.01497298} = 1.95166$$

With D.F. = 17 P = .0714 say 7 times per 100 (From Table of Student's "t" Distribution; R.A. Fisher, "Statistical Methods for Research Workers" 6th Revised and Enlarged Edition).

This means that 7 times in one hundred cases, on the average, would a difference as great or greater between k_{cold} and k_{hot} be expected just due to chance variation.

Therefore not significant.

TABLE III

ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} and k_{HOT} FOR RUNS USING WEDNESDAY'S SEWAGE ONLY. (1.0 mc/l of P^{32})

BIAS: Wednesday's Sewage Samples Only.

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.151	.213	+.062	.003844
.156	.314	+.158	.024964
.158	.149	-.009	.000081
.166	.173	+.007	.000049
.155	.157	+.002	.000004
.159	.171	+.012	.000144
.145	.167	+.022	.000484
.174	.200	+.026	.000676
.157	.158	+.001	.000001
.133	.122	-.011	.000121
.144	.138	-.006	.000036
.134	.149	+.015	.000225
		$\Sigma d = .279$	$\Sigma(d^2) = .030629$

$$\bar{d} = .02325$$

$$(\Sigma d)^2 = .077841$$

$$\frac{(\Sigma d)^2}{n} = .00648675$$

$$\sigma' d \text{ est.} = \sqrt{\frac{\Sigma(d^2) - \frac{(\Sigma d)^2}{n}}{n-1}} = \sqrt{\frac{.030629 - .0064867}{11}} = \sqrt{\frac{.0241423}{11}}$$

$$= \sqrt{.0021947545} = .04685$$

$$\sigma \bar{d} = \frac{\sigma' d \text{ est}}{\sqrt{n}} = \frac{.04685}{3.464102} = .0135244$$

$$t = \frac{\bar{d} - \bar{d}^1}{\bar{d}} = \frac{.02325}{.01352} = 1.71967$$

With D.F. = 11 P = .11778 say 12 times per 100

(From Table of Student's "t" Distribution; R.A. Fisher, "Statistical Methods for Research Workers" 6th Revised and Enlarged Edition).

This means that 12 times per hundred cases, on the average, would a difference this great or greater between k_{cold} and k_{hot} be expected just due to chance factors.

Therefore not significant

TABLE IV

ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} AND k_{HOT} FOR RUN XII THROUGH XX INCLUSIVE, PORT-RAYING MOST HOMOGENEOUS DATA. (1.0 mc/1 of P^{32})

BIAS: most homogeneous group of data.

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.166	.173	+.007	.000049
.155	.157	+.002	.000004
.159	.171	+.012	.000144
.145	.167	+.022	.000484
.174	.200	+.026	.000676
.157	.158	+.001	.000001
.133	.122	-.011	.000121
.144	.138	-.006	.000036
.134	.149	+.015	.000225
		$\Sigma d = .068$	$\Sigma(d^2) = .001740$

$$\bar{d} = .0075555$$

$$(\Sigma d)^2 = .004624$$

$$\frac{(\Sigma d)^2}{n} = .0005137777$$

$$\sigma'd \text{ est.} = \sqrt{\frac{\Sigma(d^2) - \frac{(\Sigma d)^2}{n}}{n-1}} = \sqrt{\frac{.001749 - .00051377}{8}} = \sqrt{\frac{.0013362}{8}}$$

$$= \sqrt{.000153275} = .0123805$$

$$\sigma\bar{d} = \frac{\sigma'd \text{ est.}}{\sqrt{n}} = \frac{.0123805}{3.000} = .0041268$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma\bar{d}} = \frac{.0075555}{.0041268} = 1.83085$$

With D.F. = 8 P = .1063 say 11 times per 100

(From Table of Student's "t" Distribution; R.A. Fisher, "Statistical Methods for Research Workers" 6th Revised and Enlarged Edition).

This means that about 11 percent of the time, on the average, would a difference as great or greater between k_{cold} and k_{hot} be expected just due to chance variation.

Therefore not significant.

TABLE V

A). ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} AND k_{HOT} FOR 0.1 mc/l CONCENTRATION OF RADIOPHOSPHORUS (P^{32})

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.157	.145	-.012	.000144
.133	.149	+.016	.000256
.144	.146	+.002	.000004
.134	.168	+.034	.001156
		Σd = .040	$\Sigma(d^2)$ = .001560

$$\bar{d} = .010$$

$$(\Sigma d)^2 = .0016$$

$$\frac{(\Sigma d)^2}{n} = .0004$$

$$\sigma' d \text{ est.} = \sqrt{\frac{.001560 - .0004}{3}} = \sqrt{.000386667} = .019664$$

$$\sigma\bar{d} = \frac{.019664}{2.00} = .009832$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma\bar{d}} = \frac{.01000}{.009832} = 1.01708$$

With D.F. = 3, P = .38566, say 38 per 100

Therefore not significant

B). ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} AND k_{HOT} FOR 10.0 mc/l CONCENTRATION OF RADIOPHOSPHORUS (P^{32})

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.157	.161	+.004	.000016
.133	.128	-.005	.000025
.144	.154	+.010	.000100
.134	.147	+.013	.000169
		Σd = .022	$\Sigma(d^2)$ = .000310

$$\bar{d} = .0055$$

$$(\Sigma d)^2 = .000484$$

$$\frac{(\Sigma d)^2}{n} = .000121$$

$$\sigma' d \text{ est.} = \sqrt{\frac{.000310 - .000121}{3}} = \sqrt{.000063} = .00793725$$

$$\sigma\bar{d} = \frac{.00793725}{2.00} = .003968627$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma\bar{d}} = \underline{.005500} = 1.386088$$

With D.F. = 3; P = .2649, say 26 times per 100. Therefore not significant

The reason for the use of several sewage strength dilutions, when they deviate from the 4% dilution experimentally established as the most significant (NYU-3, page 50), is due principally to weather conditions. After considerable rain or snowfall, with resulting runoff into the sewer on West Burnside Avenue where sampling is performed, a stronger dilution, such as 5%, must be made. It is realized that 4% and 5% values are generally taken as comparable in sewage dilution work, but there may exist some doubt in the minds of some of the investigators as to the validity of the assumption. For this reason Table VII, see page 24 for results, was included in this report. Actually, during all these twenty runs, only three times was the sewage considered too dilute and weak, due to prior drainage into the sewer, to utilize the material as a 4% substrate. Run XI was purposely made up as a 2.5% dilution since dissolved oxygen had to be maintained in appreciable quantity to be accurately measurable as late as twenty days after sampling of the sewage. Therefore, sixteen runs are shown in Table I with 4% sewage dilutions.

As mentioned earlier, the homogeniety of a single weekday's sewage sampling could not be maintained until October 1949. Shipping and transportation difficulties were mainly responsible for this shifting of sampling weekday.

The results of the second stage run, Run No. XI, were calculated by the slope method, which has been proven to be in excellent agreement with the method of moments. (See NYU-4, page , for discussion.) Since there are presently no tables available for the calculation of k by the method of moments for second stage work, the slope method was the only possible means. It is hoped that in the near future, during

TABLE VII

ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} AND k_{HOT} FOR RUNS USING 4% SEWAGE DILUTION ONLY. (1.0 mc/1 OF P^{32})

k_{cold}	k_{hot}	$d = k_h - k_d$	$d^2 = (k_h - k_c)^2$
.200	.250	+.050	.002500
.151	.213	+.062	.003844
.117	.222	+.105	.011025
.201	.355	+.154	.023716
.176	.192	+.016	.000256
.156	.314	+.158	.024964
.158	.149	-.009	.000081
.166	.173	+.007	.000049
.155	.157	+.002	.000004
.159	.171	+.012	.000144
.145	.167	+.022	.000484
.174	.200	+.026	.000676
.157	.158	+.001	.000001
.133	.122	-.011	.000121
.144	.138	-.006	.000036
.134	.149	+.015	.000225
		$\Sigma d = .604$	$\Sigma(d^2) = .068126$

$$\bar{d} = .03775$$

$$(\Sigma d)^2 = .364816$$

$$\frac{(\Sigma d)^2}{n} = .022801$$

$$\sigma' d \text{ est.} = \sqrt{\frac{\Sigma(d^2) - \frac{(\Sigma d)^2}{n}}{n-1}} = \sqrt{\frac{.068126 - .022801}{15}} = \sqrt{\frac{.045325}{15}}$$

$$= \sqrt{.0030216667} = .05497$$

$$\bar{d} = \frac{\sigma' d \text{ est.}}{\sqrt{n}} = \frac{.95497}{4.00} = .0137425$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma \bar{d}} = \frac{.03775}{.01374} = 2.74745$$

With D.F. = 15; P = .0158; say 1.5 times per 100 (From Table of "t" Distribution; R.A. Fisher, "Statistical Methods for Research Workers", 6th Revised and Enlarged Edition).

This means that only 1.5 times in one hundred cases would a difference as great or greater between k_{cold} and k_{hot} be expected just due to chance alone. There appears to be some significance in k values in this case, however, since it is the only analysis showing this result and no analysis has at this time been made on L_o values, further work must continue.

further progress on this project, adequate tables can be extended for the method of moments used for all of the other runs. Once this task has been accomplished the calculation of k by the method of moments can be relied upon solely, thus making the method universal in its application.

From the earlier basic work on this project, (see NYU-3, pages 5, 13, and 50), it was evident that sometimes active nitrification was already experienced on the seventh day. For this reason, when at all practicable to carry out, during the seventh day of each run determinations of NO_2-N and NO_3-N were made. Whenever the run was extended for ten, fifteen, and twenty days, except where other time sequences had to be chosen as indicated, nitrite and nitrate determinations were performed.

Table VIII, pages 26, 27, and 28, shows the results obtained from all nitrification studies. The tests are carried out according to "Standard Methods for the Examination of Water and Sewage" Ninth Edition, 1946 (8), page 120 in the case of NO_3-N by the Phenoldisulfonic Acid method, and page 121 for the NO_2-N by the Sulfanilic Acid and the Alpha-napthalamine procedure. Further data must be obtained to be able to draw any conclusions.

Sufficient data, it is believed, has been obtained on the dilution water used so liberally in all of these experiments to at least be able to infer some conclusion on this somewhat controversial matter.

At the start of the radioactive work neither sufficient bottles nor enough manpower were available to investigate the question of how radioactivity might affect the dilution water. The dilution water, as used at this laboratory, is simply composed of distilled water with

TABLE VIII

PROGRESS OF NITRIFICATION

		NO_2-N			NO_3-N		
RUN	TYPE	7th DAY	10th DAY	15th DAY	7th DAY	10th DAY	15th DAY
I	--	--	--	--	--	--	--
II	Cold	--	.070	.040	--	--	.080
	Hot	--	.040	.040	--	--	.100
III	Cold	.015	--	--	--	--	--
	Hot	.010	--	--	--	--	--
IV	Cold	.012	--	--	--	--	--
	Hot	.008	--	--	--	--	--
V	--	--	--	--	--	--	--
VI	Cold	.004	--	--	--	--	--
	Hot	.006	--	--	--	--	--
VII	Cold	.001*	.001**	--	--	--	--
	Hot	.001*	.002**	--	--	--	--
VIII	--	--	--	--	--	--	--
IX	Cold	.040	.035	--	--	--	--
	Hot	--	.030	--	--	--	--
X	Cold	.005	.040	.750	--	--	.010
	Hot	.014	.140	.950	--	--	.015
XI	See special table No. VIII - A "Progress of Nitrification for Second Stage"						
XII	--	--	--	--	--	--	--
XIII	Cold	.005	--	--	0	--	--
	Hot	.004	--	--	0	--	--
XIV	Cold	--	--	--	--	--	--
	Hot	--	--	--	--	--	--
XV	Cold	--	--	--	--	--	--
	Hot	--	--	--	--	--	--
XVI	Cold	--	--	--	--	--	--
	Hot	--	--	--	--	--	--

*3rd Day **4th Day

TABLE VIII (Continued)

RUN	TYPE	7th DAY	10th DAY	15th DAY	7th DAY	10th DAY	15th DAY
XVII	Cold	.019	--	--	.020	--	--
	0.1X	.016	--	--	.020	--	--
	1.0X	.017	--	--	.020	--	--
	10.0X	.004	--	--	0	--	--
XVIII	Cold	.009	--	--	.010	--	--
	0.1X	.010	--	--	.010	--	--
	1.0X	.013	--	--	.010	--	--
	10.0X	.004	--	--	0	--	--
XIX	Cold	.012	--	--	.010	--	--
	0.1X	0.007	--	--	.020	--	--
	1.0X	0.013	--	--	.010	--	--
	10.0X	0.003	--	--	0	--	--
XX	Cold*	.016	--	--	.020*	--	--
	0.1X*	.019	--	--	.010*	--	--
	1.0X*	.014	--	--	.010*	--	--
	10.0X*	.009	--	--	.005*	--	--

*8th Day

TABLE VIIIa

PROGRESS OF NITRIFICATION IN SECOND STAGE

	6th Day 28 Nov.	7th Day 29 Nov.	8th Day 30 Nov.	9th Day 1 Dec.	10th Day 2 Dec.	13th Day 5 Dec.	16th Day 8 Dec.	20th Day 12 Dec.
Cold NO_2	.003	.003	.005	.009	.018	.100	.44	1.44
Hot NO_2	.003	.003	.005	.007	.017	.072	.48	1.12
Cold NO_3	0	.01	.01	.01	.02	.01	.01	0
Hot NO_3	0	.01	.015	.02	.03	0	0	0

the addition of Theriault-Nichols food nutrients to simulate natural stream conditions in the laboratory. The chemicals added for this purpose are: $FeCl_3 \cdot 6H_2O$, $CaCl_2$(anhydrous), $MgSO_4 \cdot 7H_2O$, and phosphate buffer solution, the latter consisting chemically of KH_2PO_4, NaOH and $(NH_4)_2SO_4$ at a pH of 7.2.

Beginning with the VIIIth Run, on September 29, 1949, radioactive dilution blanks were incubated in parallel with the regular blanks, as can be seen in Table I, page 16. The results of twenty runs are summarized in Table IX, pages 30 and 31, giving the complete data obtained. In preparation for correlations and statistical purposes the dissolved oxygen depletions were computed for various time intervals to best study the situations. These are shown in Table IX where the data is summarized. For the complete and detailed data see Appendix A, pages 52 through 72, Table XII. To investigate the possible radiation effect of 1.69 Mev beta emitters upon the dilution water, statistical analyses were made as seen in Table X, page 32.

This type of analysis, together with the work performed to obtain this data on standard dilution water, was highly necessary in support of the main problem of the effect of radiophosphorus (P^{32}) on sewage oxidation, since no previous experiments or data on this media had been reported in the literature. The only information available on this subject is the effect of radiation on water, i.e. the production of hydrogen peroxide. A more detailed discussion on this subject is found on page 42. Any effect of this peculiar phenomenon of H_2O_2 formation on the modified Winkler Determination of dissolved oxygen is highly doubtful, if not impossible. H_2O_2 being as great, or greater, an oxidizing agent than free or dissolved oxygen alone, would show up

TABLE IX

DEPLETION OF DISSOLVED OXYGEN IN DILUTION WATER

LEGEND: (+ = Gain of D.O.) (- = Loss of D.O.)

RUN #	TYPE OF DILN H_2O	TOTAL LOSS (ppm D.O.)	TIME (days)	LOSS IN PPM. D.O. DURING		
				5 days	7 days	15 days
	Cold					
I	A parallel	+ .050	7	+ .100	+ .050	--
	B run to	- .050	7	0	- .050	--
	C cold	- .050	7	- .050	- .050	--
	D sewage	- .050	7	+ .100	- .050	--
	Cold					
	A parallel	- .150	7	+ .200	- .150	--
	B run to	- .150	7	0	- .150	--
	C hot	- .150	7	- .400	- .150	--
	D sewage	- .150	7	0	- .150	--
II	Cold	+ .050	15	- .260	- .250	+ .050
III	Cold	- .375	7	- .400	- .375	--
IV	Cold	0	7	0	0	--
V	Cold	- .200	7	- .175	.200	--
VI	Cold	- .180	7	- .330	- .180	--
VII	Cold	6.85	7	4.75	6.85	--
VIII	Cold	-1.30	15	- .300	- .950	-1.30
	Hot	-1.75	15	- .300	-1.150	-1.75
IX	Cold	- .450	15	- .400	- .450	- .450
	Hot	0	15	0	0	0
X	Cold	- .375	15	- .075	- .075	- .375
	Hot	- .350	15	+ .075	- .150	- .350
XI	Cold	-1.025	20	-1.000*	- .900	-1.125**
	Hot	-0.625	20	-0.325*	- .350	-0.075**
XII	Cold	- .300	7	- .225	- .300	--
	Hot	- .250	7	- .100	- .250	--
XIII	Cold	- .275	7	- .200	- .275	--
	Hot	+ .0375	7	- .0625	+ .0375	--

*6 days **16 days

TABLE IX (Continued)

RUN #	TYPE OF DILN H_2O	TOTAL LOSS (ppm D.O.)	TIME (days)	LOSS IN PPM. D.O. DURING		
				5 days	7 days	15 days
XIV	Cold	-.208	7	-.142	-.208	--
	Hot	-.3205	7	-.1875	-.3205	--
XV	Cold	-.300	7	-.200	-.300	--
	Hot	-.750 (?)	7	-.300	-.750	--
XVI	Cold	-.175	7	-.325	-.175	--
	Hot	-.2375	7	-.2375	-.2375	--
XVII	Cold	-.1375	7	-.1375	-.1375	--
	0.1X	-.0625	7	-.2125	-.0625	--
	1.0X	-.250	7	-.125	-.250	--
	10.0X	-.350	7	-.325	-.350	--
XVIII	Cold	-.175	7	-.150	-.175	--
	0.1X	-.150	7	-.125	-.150	--
	1.0X	-.200	7	-.150	-.200	--
	10.0X	-.325	7	-.250	-.325	--
XIX	Cold	-.2625	7	-.2375	-.2625	--
	0.1X	-.0625	7	-.1375	-.0625	--
	1.0X	-.1375	7	-.1375	-.1375	--
	10.0X	-.250	7	-.200	-.250	--
XX	Cold	-.450	7	-.325	-.450	--
	0.1X	-.450	7	-.075	-.450	--
	1.0X	-.3375	7	-.1125	-.3375	--
	10.0X	-.4875	7	-.2875	-.4875	--

TABLE X

STATISTICAL ANALYSIS TO DETERMINE THE DIFFERENCE BETWEEN RADIOACTIVE AND NON-RADIOACTIVE DILUTION WATER FOR B.O.D. TESTS

CRITERION APPLIED: THE DEPLETION IN DISSOLVED OXYGEN CONTENT IN SEVEN DAYS (1.0 mc/1 OF P^{32})

RUN	COLD	HOT	$d = \Delta_h - \Delta_c$	$d^2 = (\Delta_h - \Delta_c)^2$
VIII	-.950	-1.150	+.200	.040000
IX	-.450	0	-.450	.202500
X	-.075	- .150	+.075	.005625
XI	-.900	- .350	-.550	.302500
XII	-.300	- .250	-.050	.002500
XIII	-.275	+ .0375	-.3125	.09765625
XIV	-.208	- .3205	+.1125	.01265625
XV	-.300	- .750	+.450	.202500
XVI	-.175	- .2375	+.0625	.00390625
XVII	-.1375	- .250	+.1125	.01265625
XVIII	-.175	- .200	+.025	.000625
XIX	-.2625	- .1375	-.1250	.015625
XX	-.450	- .3375	-.1125	.01265625

$\Sigma d = .5625$ $\qquad \Sigma(d^2) = .91140625$

$\bar{d} = .04326923$

$(\Sigma d)^2 = .31640625$

$\frac{(\Sigma d)^2}{n} = .0243389423$

$$\sigma' d \text{ est.} = \sqrt{\frac{\Sigma(d^2) - \frac{(\Sigma d)^2}{n}}{n-1}} = \sqrt{\frac{.91140625 - .02433894}{12}} = \sqrt{\frac{.88706731}{12}}$$

$$= \sqrt{.0739222758} = .27189$$

$$\sigma \bar{d} = \frac{\sigma' d \text{ est.}}{\sqrt{n}} = \frac{.27189}{3.605551} = .075408724$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma \bar{d}} = \frac{.04326923}{.07540872} = 0.573796$$

With D.F. = 12 $\qquad$ P = .57756 say 58 per 100

Therefore the criterion chosen between radioactive and non-radioactive dilution water statistically not significant.

in equivalent amounts in a dissolved oxygen test by the Winkler method. For the chemistry of these reactions, the reader is again referred to page 42 of this report.

When it became obvious that there seemed to be a slight difference between the reaction rate constants, investigations along the line of influential variables that might still be eliminated or at least controlled were immediately instituted. A direct outgrowth of this situation is the recording of the temperature of the sewage sample when collected to indicate the temperature in the sewer itself. It has been reasoned that various types or strains of bacteria which may or may not be inhabitants of the sewerage system, depending upon temperature conditions, may be responsible in part or wholly for this effect on the k value. Even though the possibility seems remote at this time, the temperature is now recorded to be available for later correlation, if possible.

In order to study the effect of radiophosphorus (P^{32}) addition on the parameter k of sewage, any foreign material or carrier added with the P^{32} must also be added to the control to be able to compare and draw rightful conclusions. As indicated on page 10 , obstacles and difficulties were encountered in ascertaining the exact nature and composition of the P^{32} carrier as obtained from Oak Ridge. During the uncertain stage additions to the control were performed to the best of knowledge existing. It is now definitely established that the amount of P^{31} added along with the P^{32} is reflected by the specific activity, according to which the addition of P^{31} to the control now proceeds. In reviewing the data assembled in Table I there seems to be little or no effect due to the addition of a few ppm of H_3PO_4 or

HCl, whether this is being added according to Specific Activity or the Normality of the Oak Ridge Isotope as shipped to the various users. Table VI, page 35, shows the results being totally insignificant as to mode and material added to the control, at least for the data obtained to date.

Further data on sewage containing radioactive phosphorus (P^{32}) in the concentrations of 0.1, 1.0, and 10.0 mc/l must be obtained to be able to draw any conclusions. The same applies to the dilution water data as well as nitrification and second stage decomposition. Work along these lines is continuing.

TABLE VI

ANALYSIS OF SIGNIFICANCE OF DIFFERENCE BETWEEN k_{COLD} AND k_{HOT} GROUPED TOGETHER ACCORDING TO CONTROL MATERIAL ADDED TO THE NON-RADIOACTIVE B.O.D. RUNS. (1.0 mc/1 OF P^{32})

(1.) No Control Material Added:

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.200	.250	+.050	.002500
.217	.250	+.041	.001681
.319	.200	-.119	.014161
.151	.213	+.062	.003844
.156	.314	+.158	.024964
.158	.149	-.009	.000081
		Σd = .183	$\Sigma(d^2)$ = .047231

$$\bar{d} = .03050$$

$$(\Sigma d)^2 = .033489$$

$$\frac{(\Sigma d)^2}{n} = .0055815$$

$$\sigma' d \text{ est.} = \sqrt{\frac{.047231 - .0055815}{5}} = \sqrt{.0083299} = .091268$$

$$\sigma \bar{d} = \frac{\sigma' d \text{ est.}}{\sqrt{n}} = \frac{.091268}{2.449490} = .03726$$

$$t = \frac{\bar{d} - \bar{d}^{1}}{\sigma \bar{d}} = \frac{.03050}{.03726} = 0.81857$$

With D.F. = 5, P = .4528, say 45 times per 100

Therefore not significant

(2.) According to Specific Activity Addition with H_3PO_4:

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.201	.355	+.154	.023716
.176	.192	+.016	.000256
.134	.149	+.015	.000225
		Σd = .185	$\Sigma(d^2)$ = .024197

$$\bar{d} = .061666$$

$$(\Sigma d)^2 = .034225$$

$$\frac{(\Sigma d)^2}{n} = .011408333$$

$$\sigma \bar{d} = \frac{\sigma' d \text{ est.}}{\sqrt{n}} = \frac{.11309}{1.732051} = .0652925$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma \bar{d}} = \frac{.06166667}{.0652925} = .9444678$$

With D.F. = 2 P = .4477 say 45 times per 100

Therefore not significant

(3.) According Normality Addition with H_3PO_4:

k_{cold}	k_{hot}	$d = k_h - k_c$	$d^2 = (k_h - k_c)^2$
.166	.173	+.007	.000049
.155	.157	+.002	.000004
.159	.171	+.012	.000144
.145	.167	+.022	.000484
.174	.200	+.026	.000676
.157	.158	+.001	.000001
.133	.122	-.011	.000121
.144	.138	-.006	.000036
		$\sum d = .053$	$\sum(d^2) = .001515$

$$\bar{d} = .006625$$

$$(\sum d)^2 = .002809$$

$$\frac{(\sum d)^2}{n} = .000351125$$

$$\sigma d \text{ est.} = \sqrt{\frac{.001515 - .000351125}{7}} = \sqrt{.0001662857} = .012895$$

$$\sigma \bar{d} = \frac{.012895}{2.828427} = .00455907$$

$$t = \frac{\bar{d} - \bar{d}^1}{\sigma \bar{d}} = \frac{.006625}{.004559} = 1.45317$$

Therefore not significant With D.F. = 7 P = .1921 say 19 times per 100

IV. DISCUSSION OF RESULTS

Table II shows the statistical analysis of all eighteen k values as determined by the method of moments for the reaction velocity constant of the B.O.D. reaction. The probability of finding as great or greater a difference between the irradiated sewage and ordinary sewage parameters just due to chance (sampling and technique errors, etc.) is found to be 0.074. Thus, on the average of many runs, in seven out of one hundred cases would one expect to find the radioactive sewage parameter, k, to vary due to chance alone by .02983 units from the k of ordinary sewage, simply from these non-ascribable inherent variations. However, this value is not beyond the commonly accepted 95% level of significance, (P = 0.025 at lower end of curve) and, therefore, the test does not show that there is any significant alteration of the B.O.D. reaction rate constant by radiophosphorus. Further work must be performed to see whether or not this level shifts to a more or less significant probability before definite conclusions can be drawn on the effect of radiophosphorus (P^{32}) on sewage, sewerage systems, and treatment plants.

In seeking a more conclusive answer from the available data, further analyses were performed as mentioned previously in this report. An analysis of k values was made for all the runs on Wednesday's sewage substrate. The probability is approximately 0.12, or in 12 out of 100 cases would this great a difference in k values be attributable to chance alone. See Table III, on page 20, for analysis and results. These results are more significant in showing that no difference exists in the k values of the two sewages.

Several other tests of these k values were performed to study other possible combinations of data, based on a particular single relation among them, for possible significance of differences in k values.

Table IV, on page 21, shows the analysis and results obtained by using Runs XII through XX, which were all run on Wednesday's sewage and were run under more homogeneous conditions in all other respects than the previous runs. The probability level is found to be .1063, or 11 cases/100, which is still not significant when compared with P = .025 (the 95% level of significance).

Table V shows an analysis of the other two levels of concentrations of radiophosphorus (P^{32}) in sewage but the data is actually too meager to make any inference towards any conclusion at this time. A more convenient handling of this data, and an analysis which should show more significance will be made by the Latin Square arrangement and analysis of variance.

There are several questions, as yet unsolved, which may have given rise to the somewhat elevated k value for radioactive sewage. Among these are the variation in temperature within the sewer and the various effects of control material added to the ordinary sewage acting as the control. Therefore, Table VI, page 35, showing the results of k values correlated according to the control material added, has been included. Even this does not explain anything. Further analytical work is continuing in an attempt to get some significance out of this classification.

Another possible effect on this sewage may be due to the other foreign materials added with the isotope, even though the additions amount in magnitude, only in the order of a part per billion, or even less. However, each radioisotope shipment container has been saved in anticipation that with the passing of ten half-lives the few ml left in the container could be analyzed spectrographically. This work will be performed as soon as preparatory arrangements have been completed with other departments of this University for the use of their spectrographic apparatus. Up to the present the material was still too active to be used in the available instruments used for general chemical and physical determinations.

To further improve the quality of the data in the future, the established techniques such as mode of sewage and isotope addition, and sewage sampling weekday can now be adhered to stringently. With an increase in the quantity of this unbiased data at three levels of radioactivity, more definite conclusions should now be possible within a relatively short time.

The further elimination of variables, a goal which this project has strived for since the inception of all work, is constantly being checked. It is felt, however, that all primary variables affecting this data have either been eliminated or are otherwise controlled. Therefore, only secondary effects remain to be investigated. Such factors as purity of air used for aeration, copper in the distilled water from the still, equal periods of aging the distilled water, recording the exact times of daily B.O.D. determinations, which in the past have been assumed (first order assumption) to be taken at twenty-four hour intervals, and others.

Table XII, pages 52 through 72 in the Appendix, gives the complete data on dissolved oxygen in the dilution water used for each run. The actual dissolved oxygen values as titrated are shown. The average of each day's titrated values as well as the final value of dissolved oxygen, have been computed by an application of the least square treatment. The reason for this last column of values is to be able to calculate B.O.D. values. The dissolved oxygen in the incubated bottles loses oxygen and theoretically cannot gain any during the incubation if the temperature is constant. There is a possibility due to air microbes and other organic materials which could slightly deplete the dissolved oxygen. Therefore, a straight line relation of depletion was approximated as shown in the last column of these tables. Table XI, page 40 shows a least-square analysis of the treatment of the dilution water data for Run No. VIII. This analysis was carried out to see how closely this data conforms to a straight line. Run VIII was selected for a test case since the data appeared to provide the "worst" correlation in dissolved oxygen loss. If it could be shown that a straight line relationship adequately expressed dissolved oxygen versus time in the dilution water controls for Run VIII, it should follow that it was safe to assume a linear relationship for the other runs. As shown in Table XI the probability is > 99% that the straight line relationship represents a good fit.

As a final summary of all dilution water data, Table IX, pages 30 and 31, was prepared to show the total loss of dissolved oxygen during

TABLE XI

LEAST SQUARES ANALYSIS OF DILUTION WATER DATA

Formulation for predicted straight line $= y + bx - b\bar{x}$; $y = \left[(a - b\bar{x}) + bx\right]$

Where: $y = a + bx$ and $a = \frac{\sum y}{n} = \bar{y}$ and $b = \frac{\sum(y - \bar{y})(x - \bar{x})}{\sum(x - \bar{x})^2}$

$$= \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}}$$

From Dilution Water Date, See Table XII, page 60, Run VIII

the Correlation Coefficient of r was computed separately for the cold and hot waters to compare their fit to a straight line:

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right]\left[\sum y^2 - \frac{(\sum y)^2}{n}\right]}$$

CALCULATIONS & RESULTS:

Cold

$$r = \frac{-33.25}{\sqrt{(328.421053)(4.525)}}$$

$r = 0.8625$ D.F. = 17

P > 99.99 of straight line Correlation

Hot

$$r = \frac{-43.294444444}{\sqrt{(305.777778)(6.6824)}}$$

$r = 0.95777$ D.F. = 16

P > 99.99 of straight line Correlation

(Probability According to R.A. Fisher, Oliver & Boyd, 1936 (7), page 212)

The same Analysis was made for Run XVI, see Table XII, page 68, in which the dilution water blanks seem to show a minimal depletion, to test if the fit to a straight line would still obtain.

CALCULATIONS & RESULTS:

Cold

$$r = \frac{-3.2944444444}{\sqrt{105.777(.217462)}}$$

$r = 0.687$ D.F. = 17

99% > P > 99.9

Hot

$$r = \frac{-3.33888888}{\sqrt{105.7777(.194445)}}$$

$r = 0.742$ D.F. = 17

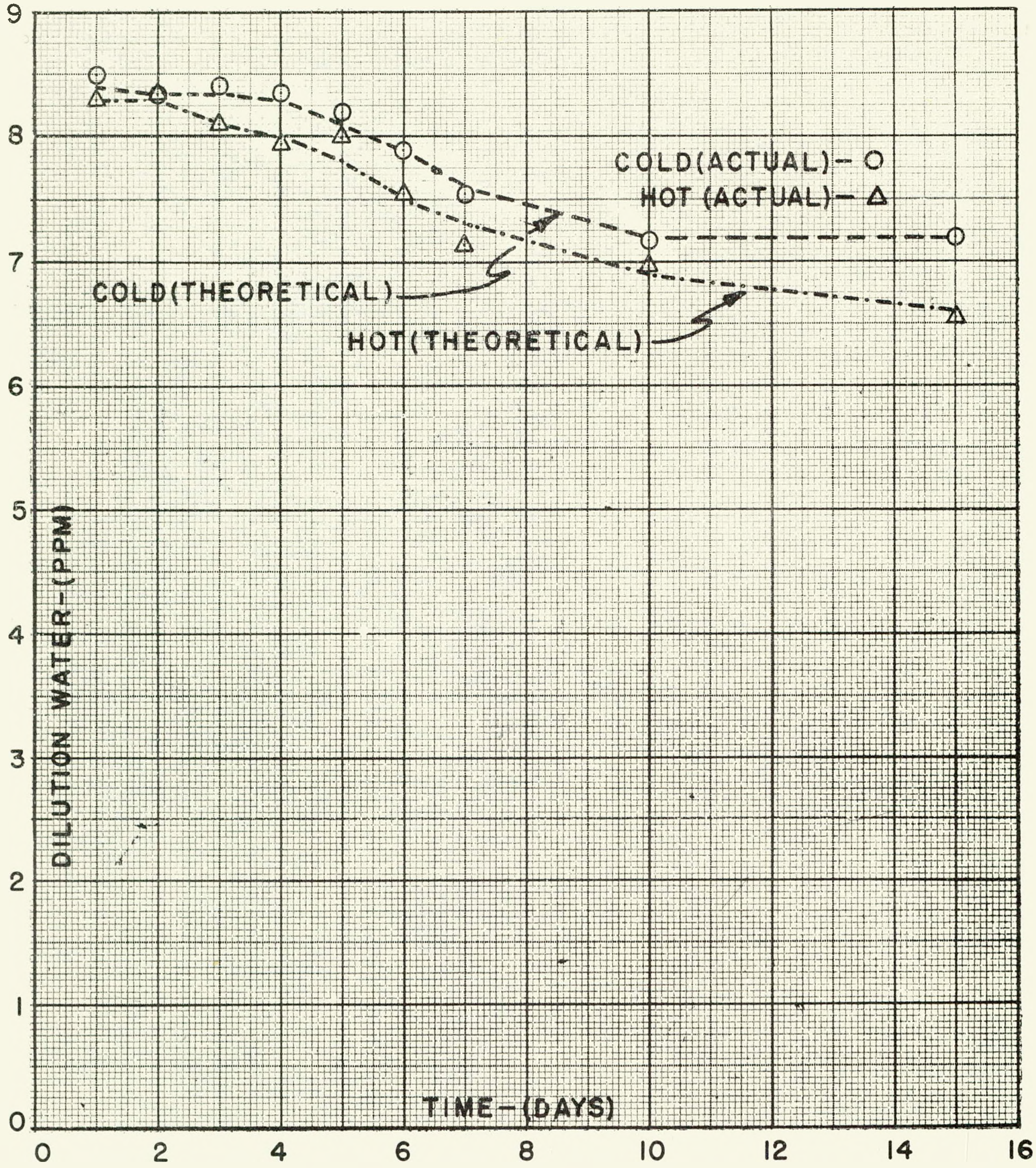
P > 99.9

The Fit to a Straight Line is therefore proven for both cases, including the worst case encountered, and it can be assumed that the other cases or Runs will show up identically. Therefore the Assumption of straight line variation is in order.

TABLE XI (continued)

The necessity for this table will be briefly discussed. In the dilution water data, necessary for consequent B.O.D. calculations, see Table XII in the Appendix, a simplified method of least squares treatment was engaged to straighten out the fluctuations of day to day observations and titrations. The established points are found under the column heading "Corrected D.O.". It is felt that this procedure, assuming a straight line variation, is entirely justified since the oxygen depletion in the dilution blanks should follow a straight line. A statistical analysis, showing the method of least squares compares excellently in linear correlation by the use of the correlation coefficient was therefore applied.

The Analysis was made on two different laboratory runs, especially chosen to portray two extremes. In Run No. VIII the dilution water showed the greatest variation from the expected and in Run No. XVI the dilution water behaves true to form, i.e. very little depletion of dissolved oxygen in 7 days. For a graphical representation see Figures I and II, pages 40 b and 40 c . In all cases, involving both regular and radioactive dilution waters, regression coefficients are found which leave little doubt that all data conform to the theoretical straight line.



Progress of Incubated Dilution Water Blanks With Time
Run No. 8

Fig. I

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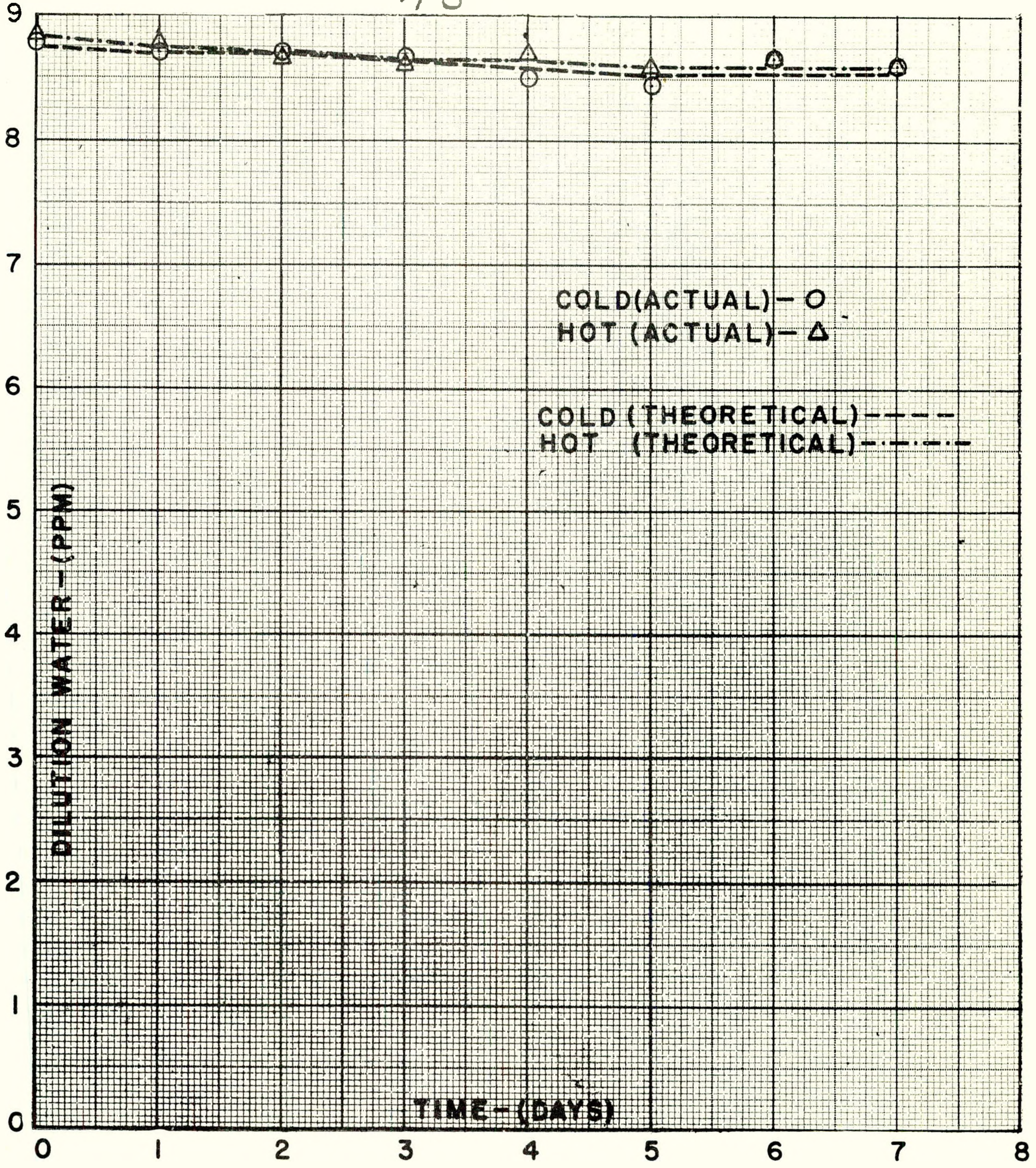

Progress of Incubated Dilution Water Blanks With Time Run No. 16

Fig. II

each run, and the five, seven, and fifteen day losses. It can be seen that, in general, the depletion of dissolved oxygen in five days is of the order of magnitude of 0.2 ppm in five days (see page 139 "Standard Methods", Ninth Edition, 1946), especially in the later runs when techniques had been improved.

Table X shows a statistical analysis on the seven-day depletions of dissolved oxygen comparing the radioactive and non-radioactive dilution water. The probability is about 58% that these variations would be due to chance alone and, therefore, the differences are not significant.

The Analysis of Nitrification studies must be deferred until more runs can be made to make the data more complete. At this time, however, a table is presented to show the data so far collected. Of all the NO_2 determinations made, an equal number of NO_2-N results (seven cases) are higher for the control media, as for the radioactive material. Nothing can, therefore, be said about NO_2-N. In the case of NO_3-N, in three cases the NO_3-N is greater for the irradiated sewage dilution and only once is the NO_3-N of the control higher. Besides, in three out of the four three-level concentration runs, the 10.0 mc/l concentration showed zero NO_3-N on the seventh day, and in the fourth case the value was only .005 ppm, or very insignificant. See Table VIII for these results, pages 26, 27, and 28.

The production of H_2O_2 by irradiation of water has been suggested as a possible error in the dissolved oxygen determination. Under those circumstances this could alter the dissolved oxygen data, B.O.D. values, and consequently have an effect on the k values.

The reactions encountered in the Winkler Method with the Rideal-Steward Modification, as used for the determination of dissolved oxygen in water and sewage are shown below:

$MnSO_4 + 2KOH = \underline{Mn(OH)_2} + K_2SO_4$ (gelatinous precipitate)

$2Mn(OH)_2 + O_2 = \underline{2MnO(OH)_2}$ (dark brown precipitate)

$MnO(OH)_2 + 2H_2SO_4 = Mn(SO_4)_2 + 3H_2O$ (acidification)

$Mn(SO_4)_2 + 2KI = MnSO_4 + K_2SO_4 + I_2$ (Iodine Liberation)

$2Na_2S_2O_3 + I_2 = Na_2S_4O_6 + 2NaI$ (Thiosulfate titration)

In these reactions the quantity of iodine liberated is equivalent to the quantity of oxygen present in the sample, the former being determined by titration with a standard solution of sodium thiosulfate.

Inspecting the photochemical reaction of $H_2O + \frac{1}{2}O = H_2O_2$ in the presence of radioactivity it will be immediately realized that since H_2O_2 is a very good oxidizing agent it will perform on $Mn(OH)_2$ just as well and in equivalent amounts as would dissolved oxygen.

An abstract of the available literature is included to indicate what seems to be known presently about the production of H_2O_2 in water containing radioactivity.

Investigation of the Production of Hydrogen Peroxide by Radioactivity

The decomposition of water by alpha-rays was first studied about 1905 and is, therefore, one of the oldest known radiation-chemical reactions. It has since become generally accepted that water is decomposed to yield H_2, O_2 and H_2O_2. Milton Burton (9) of the Department of Chemistry at the University of Notre Dame has just released a draft of a copy of an article to appear in the Annual Review of Physical Chemistry 1950, from which much of this material has been borrowed.

He has laid out the various processes which do occur in the following manner. When water is made radioactive, excited molecules and ions are produced:

$$H_2O \begin{array}{l} \nearrow H_2O^* \qquad 1\ (a) \\ \searrow H_2O^+ + e \quad 1\ (b) \end{array}$$

The excited molecules (*) may possibly decompose to yield free H and OH close together; thus:

$$H_2O^* \longrightarrow H + OH \qquad (2)$$

$$H + OH \longrightarrow H_2O \qquad (3)$$

However, the more significant reaction is the effect of H_2O^+ and the free electron produced in the reaction (1 b). The H_2O^+ reacts to produce a hydroxyl radical:

$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH \qquad (4)$$

and the free electron reacts at a distance determined by its initial velocity to give a free hydrogen atom:

$$H_2O + e \longrightarrow H + OH^- \qquad (5)$$

These free atoms and radicals cannot survive for long. They react with whatever may be available.

$$H + H \longrightarrow H_2 \qquad (6)$$

$$H + OH \longrightarrow H_2O \qquad (7)$$

$$H_2 + OH \longrightarrow H_2O + H \qquad (8)$$

$$H + O_2 \longrightarrow HO_2 \qquad (9)$$

$$OH + OH \longrightarrow H_2O_2 \text{ or } H_2O + O \qquad (10)$$

$$H_2O_2 + H \longrightarrow H_2O + OH \qquad (11)$$

$$H_2O_2 \longrightarrow \text{decomp to } H_2O \text{ and } \tfrac{1}{2}O_2 \qquad (12)$$

Careful studies have measured the gas produced from the water under irradiated conditions as well as the hydrogen peroxide. It had been shown (11) that the formation of peroxide in x-ray irradiated water came from the combination of dissolved oxygen gas from the air and water and that, if no air or other impurity was present, nothing happened to the water. Fricke found small quantities of gas, but the gases consisted of $H_2$and CO_2 rather than H_2 and O_2. The CO_2 must have risen out of the decomposition of organic impurities present in water. Fricke concluded that the best way to purify water completely is to irradiate it with x-rays.

Back Reaction in the Decomposition of Water

In the absence of any solute with which they can react, the free radicals formed by the decomposition of water will disappear by reaction with one another. If an OH radical reacts with an H atom one simply gets H_2O molecules back again, but if an H reacts with another H or an OH with another OH, the new molecules H_2 and H_2O_2 will be produced. These H_2 and H_2O_2 molecules are not found in any appreciable quantities on irradiation of pure water with x-rays, but are very much in evidence when alpha particles are used. Back reaction of those molecules that stay dissolved, when the formation of water goes on with H and OH, is pictured as follows:

$$OH + H_2 \longrightarrow H_2O + H$$

$$H + H_2O_2 \longrightarrow H_2O + OH$$

On an Atomic Energy Commission project data was obtained which has shown that with either fast electrons from a Van de Graff machine or radiation from a chain-reacting pile, one gets only H_2O_2 from water on very short exposures; oxygen appears only on longer exposures and is clearly a secondary product. It was also demonstrated that on irradiation with 1.0 Mev electrons or x-rays from a Van de Graff generator, the steady state of hydrogen and H_2O_2 concentration is reached at levels of the order of a few micromoles per liter, corresponding to a few mm's of pressure of H_2 gas above the water. The difference between alpha ray and x-ray effect has been proven to be due to differences in the steady-state concentrations of the products characteristics of the two types of radiation.

Studies at Clinton Laboratories showed that almost anything dissolved in the H_2O has the effect of increasing the amount of decomposition which can be obtained. Even Pyrex glass increases the steady-state level as do Iodine, Bromine, HCl, and HNO_3. H_2SO_4 and H_3PO_4 have very little effect if any. Oxygen reduced to peroxide under radiation is thought to undergo the following reactions (12):

$$O_2 + H \rightarrow HO_2$$

$$HO_2 + H \rightarrow H_2O_2.$$

The decomposition reaction concerns a chain:

$$H_2O_2 + OH \rightarrow H_2O + HO_2$$

$$H_2O_2 + HO_2 \rightarrow O_2 + H_2O + OH$$

$$OH + HO_2 \rightarrow H_2O + O_2 \text{ (chain termination).}$$

Peroxide competes with the hydrogen for reaction with the OH radicals, and the net yield of water decomposed at any time must depend on the relative concentrations of H_2, H_2O_2 and O_2 in solution, as well as the absolute concentration of H_2.

As can be readily observed, the picture is one of very complex reaction kinetics.

Quantitative Values

The total amount of solute reacting for any given total quantity of energy absorbed by the solution is of the order expected for the decomposition of pure compounds--that is, around one molecule reacting per 100 ev absorbed. The yield of the decomposition has approximately been established as two molecules of hydrogen gas formed per 100 ev of radiation energy absorbed by the solution (10). The concentration of H_2O_2 does not increase indefinitely as the level of irradiation goes up. The decomposition of H_2O_2 by radiation is rapid and increases with increasing H_2O_2 concentration (11).

With larger doses of radiation, the radiation proceeds according to equation:

$$2H_2O \rightarrow 2H_2 + O_2.$$

The yield of H_2O_2 during the early stages of the reaction with x-rays is known to be approximately one molecule per ion pair. If a small quantity of reducible substance appears in solution, oxygen and not hydrogen will be evolved, while in the presence of an oxidizable substance hydrogen and not oxygen will be evolved. The behavior of carefully purified water freed from dissolved oxygen is different from water which is not free from oxygen. *It seems established that the production of H_2O_2 in irradiated water requires the presence of dissolved oxygen.* If dissolved oxygen is present at the start of the experiment then production of H_2O_2, with an ionic yield of the order of unity, an evolution of hydrogen and eventually of oxygen also, begins immediately (13).

An attempt has been made of what is believed to be the worst condition of H_2O_2 production and the relative amounts of dissolved oxygen and hydrogen peroxides calculated on a theoretical and rational basis. The sample calculation is shown on the next page.

SAMPLE CALCULATIONS

for H_2O_2 Production and Comparison with Dilution Water Concentration.

Suppose: $H_2O + \frac{1}{2} O_2 \xrightarrow{B} H_2O_2$

Assume : 1 molecule of H_2O_2 formed for each 100 e.v. of Energy expended.

Greatest Concentration of Radiophosphorous used = 10.0 mc/liter

Since 1.0 mc = 3.7×10^7 d/s and B^- (P^{32}) = 1.7 Mev (no gamma)

Therefore :

$$10 \times 3.7 \times 10^7 \times 1.7 \times 10^6 \text{ ev./sec.} = 6.29 \times 10^{14} \text{ ev./sec.}$$

This is equivalent to: $\frac{6.29 \times 10^{14}}{100} = 6.29 \times 10^{12}$ molecules/second

In a day, the production of H_2O_2 amounts to: $6.29 \times 10^{12} \times 60 \times 60 \times 24$ or:

5.43×10^{17} molec./day

Total maximum production during seven days of incubation = 3.8×10^{18} molecules

thus; $\frac{3.80 \times 10^{18}}{6.06 \times 10^{23}} = 6.27 \times 10^{-6}$ moles/1/7 days

and $(6.27 \times 10^{-6})(6.06 \times 10^{23}) = 3.8 \times 10^{18}$ molecules/ liter

Assuming the dissolved oxygen concentration of the dilution water to be 8.0 ppm., this is equivalent to : $\frac{8}{32} = \frac{1}{4}$ mgmw/l

8 gms = $\frac{1}{4} \times 6.06 \times 10^{23} = 1.5 \times 10^{23}$ molecules/liter
8 mgms= $\frac{1}{4} \times 6.06 \times 10^{23} = 1.5 \times 10^{20}$ molecules/liter

Therefore, the Ratio of Oxygen to Hydrogen Peroxide Molecules equals:

$$\frac{1.5 \times 10^{20}}{3.8 \times 10^{18}} = 0.395 \times 10^2 = 40$$

Thus only approximately 1 out of 40 molecules is of the peroxide variety.

From all these deliberations it is apparent that some H_2O_2 most likely is formed in these experiments but that there would be no effect on the dissolved oxygen test by the Winkler Method. The only influence the production of H_2O_2 could have on the sewage dilution would be to act as a bactericide and inhibit bacterial metabolism. However, the results have been in the direction of a slightly higher, but not significantly different rate of dissolved oxygen uptake for the irradiated sewage.

Any effect due to H_2O_2 can, therefore, be disregarded on a rational basis. However, further investigations will be carried out to determine how this substance may actually influence the analytical technique for dissolved oxygen.

The value of conclusive results in the B.O.D. studies which are the subject of this report will be to establish whether or not the disposal of radioactive wastes into sewage will have any effect on the rate of stabilization of sewage. They should also indicate whether or not difficulties are to be expected in the treatment of sewages and wastes containing radiophosphorus (P^{32}) in the sewage treatment plant later on.

These investigations could possibly be carried out with respirometric methods such as the Warburg and Sierp apparatus to measure oxygen uptake. This method could be adapted to give continuous dissolved oxygen readings for seven or more days. It would simply require one bottle of sewage dilution for each determination. Although the respirometric methods could yield answers much more quickly, the reasons they were not used in this project are indicated below:

1) It takes several months to set up and standardize this equipment. An experienced operator is required.

2) The method has never been correlated with the standard dilution technique as practiced by this laboratory. Respirometric analysis has never been accepted as a standard method.

3) The lag period, which exerts considerable influence on the value of k, is not identical with the standard dilution technique value.

4) In plant operation, the average treatment plant operator could not operate a Warburg apparatus or anything as refined as this equipment, and the universally adopted method is the standard dilution technique for B.O.D.

5) An ensuing lawsuit, following the dumping of radioactive wastes, could not be defended properly in any court with data based on non-standard methods, such as the Warburg apparatus.

For these, and other reasons, the technique used at this laboratory was adopted and will continue to be used.

In future work on this project it would be advisable to investigate the effect of radiophosphorus (P^{32}) under other conditions such as environment, temperature, presence of solids, and other specific variables such as actually obtain under field conditions.

V. SUMMARY AND CONCLUSIONS

1. Comparing the two sets of values of k obtained for ordinary domestic sewage and sewage containing 1 mc/l of radiophosphorus (P^{32}), statistical significance of any difference is not proven by the results presently available. It will be necessary to make more runs on account of the variability of sewage and other factors which only recently have been standardized or placed under control.

2. In order to collect data which will be more homogeneous, and thus place more significance on a statistical analysis, it is felt that several outstanding variables must be dealt with strictly. The addition of sewage must be performed to give as nearly as possible the same sewage population for ordinary and irradiated sewage dilutions. The day for sampling must be adhered to, as well as the hour now practiced, 9:00 a.m. on Wednesday.

3. In studying the effect of radiophosphorus (P^{32}) on sewage, the concentration was chosen to be 1.0 mc/l as representing ten times the tentative dumping level. All early work was performed with just this one concentration. In order to gain more information, especially as to what actually would happen to the sewage and the reaction rate constant, at the level which might be later adopted, 0.1 mc/l was also investigated. 10 mc/l, representing a 100 times greater concentration, is also being studied. At the present time, however, only four runs are completed using the three levels of concentration. The results are still not numerous enough to make any real predictions, nor to make a final report on the project.

4. A statistical analysis made on seven-day depletions of dissolved oxygen indicates that there is no significant difference in the rate of dissolved oxygen depletion. However, further work is being continued to carry this problem to a successful conclusion.

5. The possible formation of H_2O_2 does not seem to have any effect on either the dilution water or the sewage dilution, from what could be ascertained to date. Further work continues, since evidence exists that H_2O_2 is formed in minute amounts, in the order of magnitude of parts per billion.

APPENDIX

TABLE XII

DILUTION WATER DATA

Run I (19 April 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	CORRECTED D.O.
Cold (Run A)	Imm	9.10	9.10
	1st	9.00	9.10
	2	9.05	9.10
	3	9.15	9.10
	4	8.85	9.10
	5	9.20	9.10
	6	9.20	9.10
	7	9.15	9.10
Cold (Run B)	Imm	9.20	9.20
	1st	9.05	9.10
	2	9.10	9.10
	3	9.20	9.10
	4	8.90	9.10
	5	9.20	9.10
	6	9.05	9.10
	7	9.15	9.10
Cold (Run C)	Imm	9.20	9.20
	1st	9.15	9.15
	2	9.10	9.15
	3	9.15	9.15
	4	8.80	9.15
	5	9.20	9.15
	6	9.10	9.15
	7	9.15	9.15
Cold (Run D)	Imm	9.20	9.20
	1st	8.95	9.15
	2	9.20	9.15
	3	9.05	9.15
	4	8.90	9.15
	5	9.30	9.15
	6	9.05	9.15
	7	9.15	9.15
Cold (Run A)	Imm	9.20	9.20
	1st	8.95	9.10
	2	X	9.05
	3	9.05	9.05
	4	9.05	9.05
	5	9.40	9.05
	6	8.95	9.05
	7	9.05	9.05

TABLE XII (continued)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	CORRECTED D.O.
Cold (Run B)	Imm	9.20	9.20
	1	9.10	9.10
	2	X	9.05
	3	8.80	9.05
	4	8.90	9.05
	5	9.20	9.05
	6	9.10	9.05
	7	9.05	9.05
Cold (Run C)	Imm	9.10	9.10
	1	9.00	9.00
	2	X	9.00
	3	9.00	9.00
	4	8.95	9.00
	5	8.70	9.00
	6	9.10	9.00
	7	8.95	9.00
Cold (Run D)	Imm	9.10	9.10
	1	9.00	9.00
	2	8.90	9.00
	3	9.10	9.00
	4	9.00	9.00
	5	9.10	9.00
	6	9.00	9.00
	7	8.95	9.00

TABLE XII

DILUTION WATER DATA

Run II (10 May 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	AVG. TITRATED D.O.	CORRECTED D.O.
Cold	Imm	8.55 8.55	8.55	8.55
	1	8.45 8.55	8.50	8.50
	2	8.45 8.50	8.475	8.50
	3	7.95 8.55	8.25	8.40
	4	8.15 8.20 8.20	8.183	8.30
	5	8.23 8.35	8.29	8.30
	6	8.40 -	8.40	8.30
	7	8.20 8.40 8.30	8.30	8.30
	10	8.20 8.30	8.25	8.30
	15	8.75 8.45	8.60	8.30

TABLE XII

DILUTION WATER DATA

Run III (2 June 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	AVG. TITRATED D.O.	CORRECTED D.O.
Cold	Imm	8.80 8.80	8.80	8.80
	1	8.80 8.70	8.75	8.75
	2	8.40 8.50	8.45	8.70
	3	8.70 8.80	8.75	8.70
	4	8.53 (?) 8.70	8.615	8.60
	5	8.30 8.50	8.40	8.50
	6	8.45 8.40	8.425	8.40
	7	8.55 8.30	8.425	8.40

TABLE XII

DILUTION WATER DATA

Run IV (15 June 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	AVG. TITRATED D.O.	CORRECTED D.O.
Cold	Imm	7.80 7.75	7.775	7.80
	1	7.80 7.80	7.80	7.80
	2	7.80 7.75*	7.80	7.80
	3	8.00 7.90 7.80*	7.95	7.80
	4	7.50 7.50	7.50	7.75
	5	7.75 7.80	7.775	7.75
	6	7.75 7.70	7.725	7.75
	7	7.80 7.75	7.775	7.75

*Composite

TABLE XII

DILUTION WATER DATA

Run V (7 July 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	AVG. TITRATED D.O.	CORRECTED D.O.
Cold	Imm	8.05 8.15	8.10	8.10
	1	8.00 8.00	8.00	8.00
	2	7.90 7.90	7.90	8.00
	3	7.85 7.85	7.85	7.95
	4	8.00 8.05	8.025	7.90
	5	7.95 7.90	7.925	7.90
	6	8.00 8.00	8.00	7.90
	7	7.90 7.90	7.90	7.90

TABLE XII

DILUTION WATER DATA

Run VI (26 July 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	AVG. TITRATED D.O.	CORRECTED D.O.
Cold	Imm	7.50		
		7.40		
		7.10	7.33	7.30
	1	7.05		
		6.90		
		6.90	6.95	7.00
	2	6.90		
		6.90		
		6.90*	6.90	7.00
	3	7.00		
		7.00	7.00	7.00
	4	6.80		
		6.90		
		6.90		
		6.90*	6.867	7.00
	5	7.40 (?)		
		7.00	7.00	7.00
	6	7.00		
		7.00	7.00	7.00
	7	7.30		
		7.00		
		7.00*	7.15	7.00

*Composite

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TABLE XII

DILUTION WATER DATA

Run VII (10 August 1949)

TYPE OF DILN H_2O	DAY	TITRATED D.O.	AVG. TITRATED D.O.	CORRECTED D.O.
Cold	Imm	7.00 6.70 6.70*	6.85	6.90
	1	6.90 6.90	6.90	6.90
	2	7.00 6.90	6.95	6.90
	3	6.50 6.50 6.40*	6.50	6.50
	4	5.50 5.50 5.30*	5.50	5.50
	5	2.10 2.10	2.10	2.10
	6	No. D.O.	-	-
	7	No. D.O.	-	-

*Composite

TABLE XII

DILUTION WATER DATA

Run VIII (29 September 1949)

	COLD			HOT		
DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	—			—		
1	8.40 7.80 ? 8.60	8.50	8.40	8.30 8.30	8.30	8.30
2	8.50 8.20	8.35	8.35	8.40 8.30	8.35	8.30
3	8.40 8.40	8.40	8.35	8.20 8.00	8.10	8.10
4	8.30 8.40	8.35	8.30	7.95 7.95	7.95	8.00
5	8.20 8.20	8.20	8.10	8.00 8.00	8.00	7.80
6	7.90 7.90	7.90	7.90	7.50 7.60	7.55	7.50
7	7.50 7.60	7.55	7.60	7.10 7.20	7.15	7.30
10	7.20 7.15	7.175	7.20	6.95 6.90	6.975	6.90
15	7.20 7.20	7.20	7.20	6.55 6.55	6.55	6.60

TABLE XII

DILUTION WATER DATA

Run IX (20 October 1949)

DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	8.70 8.70	8.70	8.70	6.50 6.60	6.55?	Assume 8.20
1	8.20 8.20	8.20	8.30	8.20 8.20	8.20	8.20
2	8.30 8.30	8.30	8.30	8.00 8.00	8.00	8.20
3	8.00 8.00	8.00	8.30	7.80 7.70	7.75	8.20
4	8.30 8.30	8.30	8.30	8.00 8.00	8.00	8.20
5	8.30 8.30	8.30	8.30	8.20 8.20	8.20	8.20
6	8.30 8.30	8.30	8.30	8.20 8.20	8.20	8.20
7	8.25 8.25	8.25	8.275	8.20 8.20	8.20	8.20
10	8.25 8.25	8.25	8.25	8.20 8.20	8.20	8.20
15	8.25 8.25	8.25	8.25	8.20 8.20	8.20	8.20

TABLE XII

DILUTION WATER DATA

Run X (2 November 1949)

DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	8.90			9.20		
	8.90			9.20		
	9.00			9.25		
	8.90	8.925	8.90	9.25	9.225	9.20
1	8.90			9.05		
	8.90	8.90	8.90	9.10	9.075	9.20
2	8.85			9.05		
	8.90	8.875	8.90	9.10	9.075	9.20
3	8.80			9.20		
	9.00	8.90	8.90	9.40	9.30	9.20
4	8.80			9.20		
	8.90	8.85	8.85	9.05	9.125	9.20
5	8.80			9.25		
	8.90	8.85	8.85	9.35	9.30	9.20
6	8.80			9.20		
	8.80	8.80	8.80	9.25	9.225	9.20
7	8.85			9.10		
	8.85	8.85	8.80	9.05	9.075	9.10
10	8.40			9.10		
	8.45	8.425	8.65	9.00	9.05	9.05
15	8.55			8.90		
	8.55	8.55	8.55	8.85	8.875	8.90

TABLE XII

DILUTION WATER DATA

Run XI (22 November 1949)

	COLD			HOT		
DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	9.10 9.00 9.10 9.10	9.075	9.10		8.75	8.75
6	8.10 8.05	8.075	8.10	8.40 8.45	8.425	8.40
7	8.20 8.15	8.175	8.10	8.40 8.40	8.40	8.40
8	8.20 8.20	8.20	8.10	8.35 8.35	8.35	8.30
9	8.00 8.15	8.075	8.10	8.05 8.10	8.075	8.20
10	8.15 8.15	8.15	8.10	8.15 8.40	8.275	8.20
13	8.10 8.15	8.125	8.10	8.40 8.40	8.40	8.20
16	8.00 7.90	7.95	8.10	7.50 8.50	8.00	8.10
20	8.05 8.05	8.05	8.10	8.20 8.05	8.125	8.10

TABLE XII

DILUTION WATER DATA

Run XII (30 November 1949)

	COLD			HOT		
DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	9.00			9.00		
	8.85			9.00		
	8.85			X		
	8.80	8.875	8.85	X	9.00	9.00
1	8.85			8.80		
	8.80	8.825	8.85	8.85	8.825	8.85
2	8.80			8.85		
	8.75	8.775	8.80	X	8.85	8.85
3	8.80			8.85		
	8.75	8.775	8.80	8.85	8.85	8.85
4	8.70			8.85		
	8.75	8.725	8.75	8.80	8.825	8.85
5	8.65			8.90		
	8.65	8.65	8.65	8.90	8.90	8.85
6	8.65			8.90		
	8.65	8.65	8.65	8.90	8.90	8.85
7	8.55			8.75		
	8.60	8.575	8.60	8.75	8.75	8.75

TABLE XII

DILUTION WATER DATA

Run XIII (7 December 1949)

DAY	COLD TITRATED D.O.			HOT TITRATED D.O.		
	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	8.80			8.45		
	8.80			8.55		
	8.75			8.55		
	8.75	8.775	8.75	8.50	8.5125	8.55
1	8.65			8.55		
	8.65	8.65	8.70	8.55	8.55	8.55
2	8.70			8.55		
	8.70	8.70	8.70	8.50	8.525	8.55
3	8.70			8.70		
	8.65	8.675	8.65	8.65	8.675	8.55
4	8.55			8.50		
	8.55	8.55	8.55	8.60	8.55	8.55
5	8.60			8.45		
	8.55	8.575	8.55	8.45	8.45	8.50
6	8.50			8.35		
	8.50	8.50	8.50	8.40	8.375	8.50
7	8.50			8.65		
	8.50	8.50	8.50	8.45	8.55	8.50

TABLE XII

DILUTION WATER DATA

Run XIV (14 December 1949)

	COLD			HOT		
DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	8.65			8.80		
	8.65			8.80		
	8.70			8.80		
	8.70	8.675	8.68	8.75	8.7875	8.75
1	8.80			8.80		
	8.80	8.80	8.60	8.75	8.775	8.75
2	8.55			8.70		
	8.65	8.60	8.60	8.70	8.70	8.70
3	8.55			8.65		
	8.55			8.60		
				8.60		
	8.50	8.533	8.55	8.60	8.6125	8.65
4	8.53			8.65		
	8.52			8.70		
	8.50	8.5167	8.55	8.70	8.6833	8.65
5	8.50			8.60		
	8.55			8.60		
	8.55	8.533	8.50	8.60	8.60	8.60
6	8.55			8.55		
	8.55			8.55		
	8.60	8.567	8.50	8.55	8.55	8.55
7	8.45			8.45		
	8.50			8.45		
	8.45	8.467	8.50	8.50	8.467	8.50

TABLE XII

DILUTION WATER DATA

Run XV (4 January 1950)

	COLD			HOT		
DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	9.10			9.30		
	9.10			9.30		
	9.10			9.30		
	9.10	9.10	9.10	9.30	9.30	9.30
1	8.90			9.25		
	8.90	8.90	8.95	9.25	9.25	9.25
2	8.95			9.20		
	9.00	8.975	8.95	9.15	9.175	9.20
3	8.90			9.05		
	8.90	8.90	8.95	9.05	9.05	9.05
4	8.95			9.00		
	9.15	9.05	8.95	9.05	9.025	9.05
5	8.90			9.00		
	8.90	8.90	8.90	9.00	9.00	9.00
6	8.80			8.95		
	8.80	8.80	8.80	8.95	8.95	8.95
7	8.80			8.55		
	8.80	8.80	8.80	X	8.55 ?	8.55 ?

DILUTION WATER DATA

Run XVI (11 January 1950)

	COLD			HOT		
DAY	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.	TITRATED D.O.	AVG. TITR. D.O.	CORRECTED D.O.
Imm	8.80			8.80		
	8.80			8.90		
	8.75			8.80		
	8.75	8.775	8.75	8.85	8.8375	8.84
1	8.65			8.75		
	8.75	8.70	8.70	8.80	8.775	8.75
2	8.70			8.65		
	8.70	8.70	8.70	8.65	8.65	8.70
3	8.70			8.50		
	8.65	8.675	8.65	8.70	8.60	8.65
4	8.55			8.65		
	8.45	8.50	8.60	8.75	8.70	8.65
5	8.45			8.55		
	8.45	8.45	8.55	8.65	8.60	8.60
6	8.65			8.65		
	8.65	8.65	8.55	8.65	8.65	8.60
7	8.60			8.60		
	8.60	8.60	8.55	8.60	8.60	8.60

TABLE XII

DILUTION WATER DATA

Run XVII (18 January 1950)

				HOT								
	COLD			0.1			1.0			10.0		
DAY	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TIT D.O.	AVG TIT D.O.	CORR D.O.
Imm	8.35			8.45			8.55			8.50		
	8.35			8.45			8.50			8.50		
	8.35			8.50			8.50			8.55		
	8.30	8.3375	8.35	8.45	8.4625	8.45	8.55	8.525	8.50	8.55	8.525	8.50
1	8.25			8.45			8.45			8.50		
	8.20	8.225	8.30	8.50	8.475	8.45	8.50	8.475	8.45	8.50	8.50	8.50
2	8.25			8.50			8.45			8.40		
	8.30	8.275	8.30	8.45	8.475	8.45	8.45	8.45	8.45	8.35	8.375	8.35
3	8.25			8.20			8.30			8.25		
	8.25	8.25	8.25	8.25	8.225	8.30	8.20	8.25	8.30	8.20	8.225	8.25
4	8.25			8.15			8.50			7.80		
				8.25			8.25			6.75		
	8.25	8.25	8.25	8.00*	8.20	8.30	8.10*	8.375	8.30	6.65*	7.275	8.20
5	8.20			8.25			8.35			8.20		
	8.20	8.20	8.20	8.25	8.25	8.30	8.45	8.40	8.30	8.20	8.20	8.20
6	8.20			8.35			8.30			8.20		
	8.15	8.175	8.20	8.30	8.325	8.30	8.30	8.30	8.30	8.20	8.20	8.20
7	8.20			8.45			8.30			8.15		
	8.20	8.20	8.20	8.35	8.40	8.30	8.25	8.275	8.30	8.20	8.175	8.20

*Composite

TABLE XII

DILUTION WATER DATA

Run XVIII (25 January 1950)

							HOT					
	COLD			0.1			1.0			10.0		
DAY	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.
Imm	8.80			9.00			9.05			8.95		
	8.80			9.05			9.05			8.95		
	8.85			9.05			9.05			8.95		
	8.85	8.825	8.85	9.00	9.025	9.00	9.05	9.05	9.05	X	8.95	8.95
1	8.70			8.95			8.90			8.90		
	8.70	8.70	8.70	8.95	8.95	9.00	8.90	8.90	8.90	8.90	8.90	8.90
2	8.70			9.05			8.85			8.80		
	8.70	8.70	8.70	8.95	9.00	9.00	8.95	8.90	8.90	8.80	8.80	8.80
3	8.60			8.85			8.85			8.80		
	8.70	8.65	8.70	8.90	8.875	8.90	8.90	8.875	8.90	8.70	8.75	8.75
4	8.80			8.90			8.95			8.70		
	8.60	8.70	8.70	8.95	8.925	8.90	8.95	8.95	8.90	8.65	8.675	8.70
5	8.65			8.90			8.90			8.70		
	8.70	8.675	8.70	8.90	8.90	8.90	8.90	8.90	8.90	8.70	8.70	8.70
6	8.65			8.90			8.80			8.60		
	8.65	8.65	8.65	8.90	8.90	8.90	8.85	8.825	8.90	8.65	8.625	8.65
7	8.65			8.85			8.85			8.65		
	8.65	8.65	8.65	8.90	8.875	8.90	8.85	8.85	8.60	8.60	8.625	8.65

TABLE XII

DILUTION WATER DATA

Run XIX (1 February 1950)

	COLD			HOT								
				0.1			1.0			10.0		
DAY	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.
Imm	9.10			9.15			9.20			9.10		
	9.10			9.20			9.20			9.10		
	9.10			9.20			9.15			9.15		
	9.05	9.0875	9.10	9.20	9.1875	9.20	9.20	9.1875	9.20	9.15	9.125	9.15
1	8.90			9.15			9.10			9.15		
	9.00	8.95	8.95	9.15	9.15	9.15	9.15	9.125	9.15	9.15	9.15	9.15
2	8.85			9.15			9.15			9.10		
	8.95	8.90	8.90	9.10	9.125	9.15	9.10	9.125	9.15	9.10	9.10	9.10
3	8.80			9.15			9.15			9.00		
	8.85	8.875	8.90	9.10	9.125	9.15	9.10	9.125	9.10	9.00	9.00	9.00
4	8.85			9.15			9.15			9.00		
	8.90	8.875	8.85	9.15	9.15	9.15	9.10	9.125	9.10	9.00	9.00	9.00
5	8.85			9.05			9.05			8.90		
	8.85	8.85	8.85	9.05	9.05	9.10	9.05	9.05	9.10	8.95	8.925	9.00
6	8.85			9.15			9.00			8.90		
	8.85	8.85	8.85	9.20	9.175	9.10	9.05	9.025	9.05	8.95	8.925	8.95
7	8.80			9.15			9.00			8.85		
	8.85	8.825	8.65	9.10	9.125	9.10	9.10	9.05	9.05	8.90	8.875	8.90

TABLE XII

DILUTION WATER DATA

Run XX (15 February 1950)

	COLD			HOT								
				0.1			1.0			10.0		
DAY	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.	TITR D.O.	AVG TIT D.O.	CORR D.O.
Imm	8.60			8.70			8.65			8.75		
	8.65			8.70			8.70			8.75		
	8.65			8.70			8.70			8.70		
	8.60	8.625	8.60	8.70	8.70	8.70	8.70	8.6875	8.70	8.75	8.7375	8.70
1	8.50			8.50			8.65			8.65		
	8.50	8.50	8.50	8.65	8.575	8.60	8.70	8.675	8.65	8.70	8.675	8.70
2	8.50			8.65			8.60			8.55		
	8.45	8.475	8.45	8.60	8.625	8.60	8.60	8.60	8.60	8.55	8.55	8.60
3	8.30			8.50			8.50			8.45		
	8.35	8.325	8.35	8.55	8.525	8.50	8.55	8.525	8.50	8.50	8.475	8.50
4	8.30			8.50			8.45			8.45		
	8.30	8.30	8.30	8.45	8.475	8.50	8.45	8.45	8.50	8.40	8.425	8.45
5	8.30			8.60			8.60			8.45	8.45	8.45
	8.30	8.30	8.30	8.65	8.625	8.50	8.55	8.575	8.50	8.45	8.45	8.45
6	8.30			8.30			8.55			8.45		
	8.30	8.30	8.30	8.50	8.40	8.50	8.55	8.55	8.50	8.45	8.45	8.45
7	8.15			8.25			8.35			8.25		
	8.20	8.175	8.20	8.25	8.25	8.30	8.35	8.35	8.40	8.25	8.25	8.25

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