BIBLIOGRAPHY AND DISCUSSION OF FLOW MEASUREMENT BY SALT-DILUTION AND SALT-VELOCITY TECHNIQUES (TURBULENT DIFFUSION OF SOLUBLE TRACERS)

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and
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Prepared under
U. S. Bureau of Reclamation Contract D-293
Denver Federal Center
Denver, Colorado

Engineering Research Center
Colorado State University
Fort Collins, Colorado

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BIBLIOGRAPHY AND DISCUSSION OF FLOW MEASUREMENT BY SALT-DILUTION AND SALT-VELOCITY TECHNIQUES (TURBULENT DIFFUSION OF SOLUBLE TRACERS)

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I. INTRODUCTION

Engineering papers dating back as far as 1863 deal with streamflow and pipeflow measurements utilizing dilution techniques. At that time Schloesing, using techniques of quantitative analysis, determined the amount of dilution that had occurred when a known quantity of ammonium sulphate was injected into a stream. Knowing this, he was able to determine the discharge with sufficient accuracy. Allen's salt velocity method is known all over the world. Although many individuals are aware of these methods, few are cognizant of their value and potential in modern technology. Considerable progress has been made in recent years by way of improving these methods but there has been a tremendous amount of duplication in research and practical investigation.

This report was prepared in order to bring to the profession a bibliographical survey of these methods to avoid loss of time in the search for the references and further duplication of effort in future studies. At present no survey of published literature on this subject is available.

The subject matter included herein relates to salt-dilution and slat-velocity techniques involving any sort of a soluble tracer such as salt, other chemicals, dyes, radioisotopes, etc. Also included herein are some references on turbulent diffusion of soluble tracers in conduits and a few of the classical works in turbulent diffusion. Since constant flow metering devices are so important to these methods, several

papers dealing with such methods have been included. The bibliography is arranged chronologically and contains abstracts of papers that were available within the time limits set for this project. The papers and articles are also indexed according to authors and subject matter. Also included are papers which have some general bearing on the problem of discharge dilution gaging methods. These are included in the author index in a separate section as having a general bearing on the problem.

II. SALT-VELOCITY METHODS

Allen's salt-velocity method originally made use of electrical conductivity to detect brine concentrations. By passing a brine cloud between two pairs of electrodes located at different axial positions along the stream the variation of conductivity could be determined as a function of time. From this, the time at which the center of the brine cloud passed could be determined. Knowing the volume of the stream between the two points and the travel time, the discharge or mean velocity could be calculated. Since then many time of travel studies have been made in pipes, channels and estuaries. While the method of detection and the tracer may vary considerably, the fundamental simplicity of the method remains unchanged. It is, however, largely dependent upon a knowledge of stream or conduit geometry for determination of the volume and is, therefore, less adaptable to many situations than are the salt-dilution methods.

III. SALT-DILUTION METHODS

This method, credited originally to Schloesing, goes by many names such as chemical dilution, dye dilution, isotope dilution, etc. Modifications of these are called constant-rate injection and total-count method or total-recovery method. Basically these methods require that some substance, soluble in the fluid to be measured, be introduced

into the flowing fluid and samples taken downstream of the diluted substance after it has nearly completely mixed with the water. The substances most commonly used have been salt, other chemicals, radioisotopes and dyes but any material readily soluble and easily detectable in small concentrations could be used. Some progress has been made in the use of activation analysis. This involves taking a non-radioactive chemical of known quantity and concentration and later determining the diluted concentration by making the element radioactive through neutron bombardment. The concentration of the element can then be easily determined even though present in small quantities. This method is most attractive in principle since very small concentrations can be measured and yet no radioactive material needs to be dumped into the stream or conduit.

Quite naturally the means of detecting the tracer vary considerably but the underlying principle is the same. In the case of salt dilution, the detection may be through quantitative analysis or electrical conductivity measurements. For radioisotopes, Geiger-Mueller instrumentation or scintillation detectors would be used. For dyes, colorimetric, photometric or fluorometric detectors would be used. While there are many pros and cons regarding the best method, it would appear that salt methods are impractical for large discharges although the instrumentation is comparatively simple, because large quantities of salt are required. Radioisotope methods require expensive and elaborate instrumentation and considerable red-tape in obtaining licenses and permission for use but they probably provide the ultimate in precision. Dyes, particularly fluorescent dyes are cheap, can be detected easily in very small concentrations (less than 1 part per billion) and require comparatively simple instrumentation. Their accuracy is probably not as good as that of the radioisotope methods.

There are two basic ways of determining discharge by dilution. In the constant-rate injection method a soluble tracer solution is injected into the flowing stream at a rate q and a concentration C_1. Downstream at a point where the tracer has been completely mixed with the concentration C_2, the diluted solution is measured. By continuity:

$$qC_1 + QC_o = (Q + q)\, C_2 \tag{1}$$

where C_o is any background concentration present in the water and Q is the discharge which is to be determined. When this equation is solved for Q, one obtains:

$$Q = \frac{C_1 - C_2}{C_2 - C_o}\, q\,, \tag{2}$$

and in the event that $C_o = 0$ and $q \ll Q$, the equation reduces to:

$$Q = \frac{C_1}{C_2}\, q\,. \tag{3}$$

Another method is to dump all of the tracer into the stream in a cloud. Then downstream at a point where the tracer is nearly completely mixed (laterally), a concentration time curve is obtained for the entire cloud as it passes by. The discharge can then be calculated from the relationship:

$$Q = \frac{VC_1}{\int_o^\infty (C_2 - C_o)\, dt}\,, \tag{4}$$

where V is the volume or amount of the tracer solution dumped into the stream. The integral represents the total area under the time-concentration curve with the background subtracted. This may be obtained from a graphical integration of a continuous record of concentration or may be approximated by a histogram in the event that discrete samples are taken. The method completely breaks down if mixing is not complete. Because of the reliance of these methods on completeness of mixing, many authors have made both analytical and experimental

attempts at predicting a mixing length. Such literature has been reviewed and abstracted in this text. The accuracy of the constant-rate injection method is fundamentally dependent upon the accuracy with which the tracer can be metered into the flowing stream. Papers dealing in part or in whole with such constant flow devices are also reviewed here.

IV. TURBULENT DIFFUSION

Since the first paper by G. I. Taylor on diffusion by continuous movements, considerable progress has been made in the field of turbulence and turbulent diffusion. Much work has been done in dispersion studies both in pipelines and in streams. No attempt was made to review all of these papers. A few of the classical papers necessary as a background for anyone who wishes to read the turbulence literature are included herein. Included also are some of the more recent outstanding works in turbulent diffusion which offer rational equations for the determination of mixing distance.

V. BIBLIOGRAPHY

The explanations and remarks contained in this introduction are intended to provide the reader with a very brief sketch of its scope and aid in its use. The subject matter is mainly that of dilution methods of flow measurement both in the laboratory and in the field and includes classical papers, recent papers, reports of studies made and references to papers that are restatements summarizing the results of previous studies. The bibliography also includes some papers on turbulent mixing and diffusion.

VI. FORMAT

Each reference in the bibliography is identified by number, author(s), year, language (if other than English), title, journal, volume and for books, the publisher's name and location. For these references given in other languages, the title is given in the original language followed by its English translation.

Abstracts included herein that are not restatements, are generally informative rather than merely descriptive. The abstracts contained in this bibliography were either made by the compilers, or are the author's own abstract in the event that his abstract was an adequate summary with respect to the context of this bibliography.

The bibliography is arranged chronologically and includes the abstracts. Separate indices are provided for subject matter and authors. Some papers which are not directly applicable but may be useful in a broad sense are included in a separate section but are indexed only according to author. Papers not available for abstracting were also included but without the abstract.

VII. CHRONOLOGICAL BIBLIOGRAPHY AND ABSTRACT

1. Schloesing, M. Th., 1863, (French), Nouvelle méthode pour jauger les fluids (New method for gaging fluids). Comptes rendus hebdomadaires des séances de l'Academie des Sciences, 57:164-166.

The basic idea is flow measurement by dilution method. For a fluid flow rate, Q, a chemical is introduced through the small flow rate, q, of a given concentration. Then the diluted concentration is measured. From q and the two concentrations, the flow rate Q is determined. The calcium and sodium chlorides are recommended as the chemicals to use.

2. Stromeyer, C. E., 1896, Measuring water chemically. The Engineering Record, 34 (n. 17):314.

This article is a discussion of an experiment performed by Mr. C. G. Stromeyer in which he used sodium chloride to measure water flow rate and obtained results accurate within 4 per cent.

3. Martel, E. A., 1903 (French), Sur l'application de la fluoresceine à l'hydrologie souterraine (On the application of fluoresceine to groundwater hydrology). La Houille Blanche, 2 (n. 3):286-287.

The properties of fluoresceine are enumerated in relation to their fitness in connection to detection of water courses. The conditions set up and the results obtained in the undertaking of field measurements are described.

4. Ribourt, L., 1903, (French), Méthode et appareils de mesure pour turbines hydrauliques (Method and measurement equipment for hydraulic turbines). La Houille Blanche, 2 (n. 11), Nov:336-341.

Two methods of flow measurement through turbines are discussed; (a) Installation of a recording volumetric current meter with accessories, and (b) Gaging of discharge in penstocks by using dye with the detection tubes. (In this second method, the dye injection travel time between two points is determined by recording the passage of the dye.)

5. Iterson, F. K. Th. van, 1904, (French), Méthode chimique pour la mesure du débit (The chemical method for discharge measurement). Le Génie Civil (France), 44 (N. 26):411-412.

In this paper, the chemical method of discharge measurement is briefly compared with other methods for discharge measurements. By injecting the chemical at the inlet of mechanical devices (fans, pumps, turbines, etc.) a fast mixing of chemical is obtained.

6. Anonymous, 1905, Chemical gauging of streams. The Engineering Record, 52 (n. 17):454.

A news article. This essay stresses the applicability of the chemical method of flow measurement to many problems. Several uses are cited such as measurement of boiler feed water and streams and rivers. Comparisons are given of rate measurements obtained in this way with those obtained by other methods. (Reference is made to a paper by Stromeyer presented at the meeting of the Institution of Civil Engineers).

7. Eutcher, W. L., 1905, The gaging of streams by chemical means. Engineering News, 54:634-635.

Rasin dye, soluble in water, can be used as a solution for gaging streamflow. Described is the method based on a constant injection rate made possible by the use of a floating siphon.

8. Stromeyer, Charles Edmond, 1905, The gauging of streams by chemical means. Proceedings of Institution of Civil Engineers, London, 160:349-363.

Stream gauging by the chemical method was made possible by the injection, at a uniform and accurate rate, of a concentrated chemical solution into a stream in which the water was analyzed before and after the injection. The author suggests that the tests preferably should be carried out at the most irregular section of the stream, and that for a better mixing the two sampling stations should be placed far apart. The paper further includes the description of experiments performed by the author and some other investigators.

9. Lemaire, E., 1911, (French), Mesure du débit des cours d'eau par les méthodes chimiques (Measurement of discharge of streams by chemical methods). Le Genie Civil (France), 58(n. 24):497-500.

The use of the chemical method (dilution method) for flow measurement in streams is set forth in great detail. The conditions for selection of chemicals, the amount of salt needed for a given river flow measurement, and other problems are covered. Several apparatuses for the constant flow or constant velocity of the chemical dosage are analyzed and described. Many details of measuring technique are presented, and a discussion of the precision of the method included. The method of using dyes (active dyes, fluoresceine, and others) is also discussed.

10. Schoder, E. W., 1911, Mixing, diluting or contaminating effects with liquid flow in pipes. The Cornell Civil Engineer, 20(n. 3):122-127.

The author gives an account of tests investigating the mixing of liquids in pipe lines. According to his conclusions, mixing mainly occurs because of a non-uniform velocity distribution which results in dilution of the faster moving liquid in the center of pipes by adjacent fresh portions ahead of it.

11. Schloesing, Th., 1912, (French), Jaugeage de cours d'eau par l'analyse chimique (Gauging of a stream by chemical analysis). Comptes rendus hebdomadaires des séances de l'Academie des Sciences, (France), 155 (n. 17):750-753.

The author first reviews his proposal of 1863, and then explains experiments with measuring the saline water discharge. He used ammonium as the chemical in the flow measurement and the full results of his experiments are presented.

12. Schloesing, Th., 1912, (French), Jaugeage par l'analyse chimique (Water measurement by chemical analysis). La Houille Blanche, 11 (n. 12):325-326.

The author proposed in 1863 the use of the salt method in measuring water flow (communication to French Academy of Sciences in 1863). In this 1912 paper, the author gives again his equation $V = v(Q/q - 1)$, where V = flow rate in a canal, v = flow rate of salt solution, Q = salt concentration in the added salt solution, and q = salt concentration in the canal after dilution. In addition, the experiments made by the author in applying his approach are described.

13. L. G. L., 1913, (French), Mesure du débit d'une turbine hydraulique par la méthode chimique (Measurement of discharge of a hydraulic turbine by the chemical method). La Technique Moderne, 7 (n. 4): 133-134.

The details of an experiment in measuring flow rate through a hydraulic turbine using ordinary salt is described. The fluctuations of salt concentration in diluted tailrace water as a function of time are given; they show a relatively constant concentration.

14. Mellet, R., 1913, (French), Le jaugeage des débits par voie chimique (Flow measurement by the chemical method). Révue Générale des Sciences Pures et Appliquées, 13 (n. 21):809-816.

The principles basic to applying the salt dilution method of flow measurement are outlined in this study. Also, a device to obtain the constant rate of injection of the initial solution is described. The techniques used in performing the measurements are discussed in detail, and a claim is made that this method gives a precision of 1 per cent. Next, the salt dilution method is compared with the current meter method, ecran method, and weir method. For this, measurements of the discharge through a hydroelectric power plant are given. At the end, the author asserts that "without any difficulty a precision of 0.1 per cent can be obtained in discharge measurement," a conclusion which, however, never has been even approximated in later more precise experiments.

15. Anonymous, 1914, The titration method of measuring fluid flow. Electrical World, 64 (n. 1):481.

Tests were made on a low head turbine installation at Croton, Michigan, for the Grand Rapids and Muskegan Power Company. The turbine had 8 runners and operated at 225 rpm under 39.5 feet of head. Brine solution was injected into the turbine and samples were collected at the tailrace. A comparison of discharge with that measured by an Epper-Ott current meter showed a 1.3 per cent difference.

16. Collet, L. W., R. Mellet and O. Liitschg, 1914, Jaugeages par titrations (Stream gaging by titrations). Comparative tests of new chemical and standard mechanical methods of gaging stream flow. Engineering and Contracting, 42:270-273.

This paper discusses the use of the titration method in measuring the flow in a turbine at the plant at Ackersnad, near Viege. The

constant rate method was used with salt solutions as a tracer. Comparisons were made with the current meter, the curtain method, and the weir. The plant in Switzerland has a tailrace equipped with a curtain or screen for measuring the discharge of turbines according to the method of Prof. Anderson of Stockholm. Three conditions were stated as necessary for the success of the gaging: (1) constant rate of flow of the initial solution; (2) perfect mixing; and (3) accurate titration of the salt solution. The ratio of the initial solutions to the approximate discharge of the turbine or the stream was suggested as 1 to 10,000. The results of the experiments where Q was given in liters per second were as follows:

Salt solution	current meter	curtain	weir	
1356.5	1317.5	1303.0	1339	Salt solution poured into the turbine.
1305.2	1291.0	1299.0	1312	Salt solution poured into the tailrace.

17. Groat, B. F., 1914, Water discharge measurement with chemicals. The Engineering Record, 70:208-209, 246-247.

The general formulas for constant injection rate are derived and discussed. Gravimetric and volumetric methods of titrating sodium chloride solutions with silver nitrate are described in detail with due attention given to their advantages and pitfalls. The effects of other chemicals naturally present in the stream are considered and a method suggested for overcoming this source of error. It is also noted that silver nitrate may react with the indicator, and the method of Mellet of the University of Lausanne is described in which this effect is compensated for so that the reaction quantities will cancel from the resulting equations. An actual test made by Mellet on a turbine at the Day Power Plant at Vallorbe is recounted in intricate detail.

18. Iterson, F. K. Th. van, 1914, (Dutch), Chemiche methode van watermeting (Chemical method of water discharge measurements). De Ingenieur, 29 (n. 32):608-609.

An experiment is described in which a sodium hyposulfite solution was introduced into the inlet of a centrifugal pump and the discharge determined by titration of the diluted solution. Earlier the author had not used a constant injection rate in his experiments, and this article was a reply to those who had criticized him for this. Also described are two constant head, constant flow devices for metering salt solutions. The author explains how he took the unsteady flow rate of the salt solution into account in determining the water discharge.

19. Iterson, F. K. Th. van, 1914, Chemical method of water measuring. Engineering, 97 (n. 2526):743.

A letter to the editor discussing the use of the chemical method in measuring discharge in pipelines and pumping systems. Iterson remarks that in former articles the method had been ascribed to Boucher but that actually the method had been in use in Holland for several years. The paper describes a method in which injection is in the suction line leading to the pump, and it contains some sketches of equipment. According to the article, in areas where the drainage water which is pumped contains soldium chloride, another chemical soldium hyposulphite is used.

20. Streiff, A., 1914, Measuring turbine discharges with salt solutions. The Engineering Record, 69 (n. 5):143.

A classic and historical discussion of the use of dilution methods and chemical analysis in measuring fluid discharge, this paper discusses Schloesing's early work and also that of van Iterson, Lemaire, Stromeyer, Cote, Bellet, and Boucher. The work of Collet in testing Francis turbines at 1000 ft^3/sec is also described.

21. Streiff, A., 1914, Testing low-head turbines by the chemical method. The Engineering Record, 70 (n. 10):276.

The water consumption of a 7200 hp. horizontal, eight runner water turbine running at 225 rpm and operating under a head of 39.5 ft was measured by the chemical method. The water consumption was found to be 2140 sec.ft. The salt solution was injected directly into the turbine. It was found that a perfect mix was obtained, not withstanding the fact that the place where the samples were taken was in the tailrace. The final calculations showed a difference of 1.3 per cent with the results obtained by Ott meter measurement.

22. Wingfield, C. H., 1914, Chemical method of water measuring. Engineering, 97, :773.

To the editor of Engineering: Sir, --- Mr. F. Van Iterson on page 743 of your last issue claims that as this method of water measurement has now been in use in Holland "for several years", it is incorrect to ascribe its invention to Boucher. I think he will find the credit of originating it is due to Mr. C. E. Stromeyer, the very versatile chief engineer of the Manchester Steam Users Association. A paper written by him appeared in 1896 on page 225, vol. XXXVII of the proceedings of the institution of Naval Architects in which he described its

application to the measurement of feed on circulating water. Another in 1905 on "Gauging Streams by Chemical Means" will be found on page 349, vol. CLIX, of the proceedings of the institution of Civil Engineers. In this, Mr. Stromeyer described a simple method of ensuring constancy of flow of the chemical solution into the system, obviously a very important point. Yours faithfully, C. H. Wingfield.

23. Anonymous, 1915, Salt solution test shows turbine efficiency of 93 per cent at Holtwood Plant. The Engineering Record, 71:358-360.

The chemical or titration method of determining the turbine discharge described in the Engineering Record of Jan. 31, Aug. 22, and Aug. 29, 1914 was used to ascertain the efficiency of a single runner turbine, with vertical shaft installed at the Pennsylvania Water and Power Company electric plant at Holtwood, Pa. The rating is 16,500 hp at 63 ft head. The equation $Q = (N_o \times q)/(N_2 - N_1)$ was used and concentrations were determined by titration in accordance with the method developed by Dr. R. Mellet of Lausanne, Switzerland. Since there were four separate intakes for each turbine, four horizontal distributing pipes were arranged at different elevations in each of these four intakes, resulting in a fairly uniform discharge of the salt throughout the intake. These horizontal pipes were connected through vertical pipes to a common into which the centrifugal pump discharged the salt mixture. Samples were taken in the tailrace after the water had passed through the turbine; each test lasted generally from 8 to 10 min. and would require approximately 3 tons of salt.

24. Groat, B. F., 1915, Chemi-Hydrometry and its application to the precise testing of hydro-electric generators. ASCE Transaction, 80:951-1305.

The chemical method, based on the original suggestion by Schloesing in France in 1863, was used in testing large-capacity turbines where a discharge of several thousand cubic feet per second could be measured with precision. This paper contains the formula which leads to the method of balanced evaporation. The coefficient of shrinkage of volume when two salt solutions are mixed is fully treated and tabulated. Moreover, theoretically correct equations, involving concentrations only, are established.

25. Peaslee, W. D., 1915, The saline method of water flow measurement. Journal of Electricity, Power and Gas, 35 (n. 8):130-135.

This paper is a description of the techniques and theory of the salt-dilution method of flow measurement.

26. Peaslee, W. D., 1915, The saline method of water flow measurement, conductivity method. Journal of Electricity, Power and Gas, 35 (n. 9):148-149.

In search of an easier method of flow-measurement, Mr. Peaslee investigated the conductivity method whic is based on the principle that the conductivity of a solution is proportional to the concentration of ions present in the solution. Using a potentiometer he developed a curve relating the salt concentration to the solution conductivity.

27. Peaslee, W. D., 1916, The saline method of water flow measurement as used in the acceptance test of a pumping plant. General Electric Review, 19 (n. 2):132-138.

The author begins with the equation: $V_oS_o = (V_2 + V_o)S_2$. If the volume to be measured contains some of the chemical used in the dosing solution, this content must be determined. Calling it S_3 , the equation becomes: $(V_oS_o + V_2S_3) = (V_o + V_2)S_2$. Expressed in terms of discharge, this becomes $Q = q(S_o - S_2)/(S_2 - S_3)$. To determine the amount of salt per unit volume in each sample, the method of precipitating the salt with silver nitrate ($AgNO_3$) was used. The plant tested was one installed to drain a 1000 acre "beaverdam" lake at Gaston, Oregon. The pump was a 30-in. vertical centrifugal pump rated at 32,000 gallons per minute at eight feet normal head. Four five-minute runs were made and the dosing solution introduced in each run at the rate of 0.775 liters per second. Samples were taken at the pump discharge.

28. Taylor, G. I., 1921, Diffusion by continuous movements. London Mathematical Society, Proceedings, 20:196-211.

This classical work should be read by anyone seriously interested in turbulent diffusion. In it, Taylor showed how the characteristics of the distribution of the diffusing substance can be related to the Lagrangian velocity correlation coefficient for the case of homogeneous turbulence. This turbulence study has an important bearing on chemical dilution method of discharge measurements.

29. Allen, Charles M., 1922, Salt-velocity method of measuring water in pipelines. Engineers and Engineering, 39 (n. 6):196-197.

This paper is a brief introduction to the salt-velocity method, which was presented by Professor Allen in 1922. He mentions in his paper that the time of maximum density gives the correct mean velocity. He conducted his tests in 13" wood stave lines 1400' long, and in a 40" steel riveted pipe 400-500' both before and after cleaning.

30. Anonymous, 1922, Salt-velocity method for measuring flow of water in pipe lines. Engineering and Contracting (W. W.), 58:358.

The paper states that the experimental work in measuring the flow of water through pipes by injecting salt solution and timing its passage gives promise of an accurate method for measuring water according to a paper by Prof. Charles M. Allen. The paper then gives a summary of the Allen method.

31. Joly, J., 1922, On a new method of gauging the discharge of rivers. The Scientific Proceedings of the Royal Dublin Society, New Series, 16 (n. 37):489-491.

In this essay, the uses of "chemical hydrometry" in river flow measurement are presented. In experiments, a salt solution of known concentration was injected into a stream, and the salt concentration of a sample taken downstream was determined by titration. The resulting accuracy was reported to be 1 per cent.

32. Crewdson, Eric, 1923, Velocity of flow by the salt method. Chemical and Metallurgical Engineering, 30:59-60. Chem. Abs., 18-1: 1022 (1924).

The time of arrival of salt solution at the lower end of a pipe was indicated by the reduction in electrical resistance between two electrodes fixed in the pipe and in contact with the water. A set of tests was made on a turbine installation by Gilbert Bilkes and Co., Ltd., for Captain W. Best at Vivod Llangollen, North Wales, in a cast iron pipe 2400 ft long, part of which had a 12" diamter and part 9". The 12" portion was at the upper end. A direct current at 110 volts was applied through a volt meter to each pair of electrodes, which were ordinary spark plugs, slightly modified. The quanitity of the salt solution introduced into the pipe for each observation was about 1 gallon and the time occupied in the introduction of the salt was about 5 seconds in each case. It was found that as the salt passed each pair of electrodes, the corresponding voltmeter began to drop at first rapidly and then more slowly. The salt was introduced about 20 yards from the reservoir outlet; the lower pair of electrodes was screwed into the pipe just after it had entered the power house and before it reached the turbines.

33. Houk, I. E., 1923, Electrical measurement of velocities of flow in pipes. Engineering, 115 (n. 2995):644-645.

A general discussion of the use of the salt-velocity method for measuring flow rate through dredge pipes in construction of flood prevention dams in the Miami River Valley in Ohio. The pipes were 15 in. to 18 in. wooden stave construction 800 to 2100 feet long; velocities were of the order of 7 to 18 feet per secons, and a pound of salt was used per 15 cfs. The author also discusses the use of the salt-velocity method by the Bureau of Public Roads and U. S. Department of Agriculture.

34. Allen, C. M. and E. A. Taylor, 1924, The salt velocity method of water measurement. Mechanical Engineering, 46 (n. 1):13-16, 51.

According to the authors, the passage of salt solution between two points can be accurately timed using one or more pairs of electrodes. The theory and development of the method are outlined, and the article includes a description of the apparatus used both in the laboratory and in the field. Computational procedures are discussed and an account is given of several commercial tests. Stress is on the accuracy and reliability of the method.

35. Will, G. M., 1924, Salt-velocity stream-flow measurement. Electrical World, 83:1285.

The Allen method (salt-velocity method) was used by the Southern Sierras Power Company for measuring the water velocity in the flow line at one of its hydro-electric plants at Bishop, California. The purpose of the test was to check the accuracy of a venturi meter which had been installed. The flow line in question was a 60 in. wooden-stave pipe. Two sets of electrodes were placed in the line through stuffing boxes a distance of 2,000 ft apart. A small amount of concentrated solution of salt water (four or five gallons) was introduced into the pipe line a short distance above the upper pair of electrodes. Then a stop watch was used in checking the time of flow between the points. The time of the maximum influence on the electrode was used in calculating the flow of water in the pipe. A comparison of this record with that of the venturi meter gave a check on the accuracy of the meter.

36. Mueller, E. Karl, 1926, (German), Die Salzgeschwindigkeits-Methode von Allen zur Wassermessungen in Rohrleitungen (Allen salt velocity method for measuring water discharge in pipes). Schweizerische Bauzeitung, 87 (n. 4):41-44.

In this essay, the Allen salt-velocity method for flow measurement in pipes is reviewed with the following aspects emphasized: the principles of the method, the practical measurements, theory of method and the various sources of errors.

37. Allen, C. M., 1927, Hydraulic-turbine tests by the Allen method. Power Plant Engineering, 31 (n. 10):549-551.

In experiments outlined in this paper, an increase in the electrical conductivity of water due to the introduction of a salt solution was used as the basis for measuring the volumetric rate of flow of water. The passage of the salt cloud across electrodes was recorded graphically on charts by an electrical instrument, and thus the time of travel of the salt cloud between two electrodes could be measured. A detailed description of the conduct of the tests, the method of computation, and the analysis of results obtained are given. The tests were conducted on four units to determine the discharge, horsepower, and efficiency of the wheels and also to calibrate venturi meter sections. Pop-valves were used for the salt solution injection, and the center of gravity of the conductivity chart was employed in calculating the time of travel.

38. Finlayson, J. N., 1927, Experimental determination of hydraulic constants in a large aqueduct; a series of tests to determine the discharge of the greater Winnipeg Water District concrete aqueduct by the use of the salt-velocity method. Engineering Institute of Canada, Journal, 10 (n. 6):297-301.

The aqueduct, nearly 100 miles long, is of the open flow type except at river crossings. It has a maximum capacity of 85, 000, 000 imperial gallons per day. The discharge determinations by salt velocity, venturi meter, and current meter were compared. Sites were chosen about 1 mile between injection and sampling stations. Then, salt concentration was determined by electrical conductivity and the center of area method was used to determine discharge. The following results were given in millions of gallons per day:

Venturi Meter	Current Meter	Salt Velocity
30	33. 45	32. 5
67	70. 20	68. 1
80	80. 98	81. 4

The roughness of the aqueduct was estimated at . 013.

39. Barbagelata, A., 1928, Chemical-electric measurement of water. ASCE Proceedings, 54 (n. 3):789-802.

The salt solution method is described in which the concentration is measured by chemical titration or by electrical conductivity. Changes in conductivity are determined by use of a wheatstone bridge circuit. The equations for calculating discharge are: $Q = q(C_1 - C_2)/C_2$ and $Q = qC_1/C_2$. The writer metnions that even after passage through a 70 meter length of pipe, a turbine, and 10 meters of tailrace, solutions introduced into a single jet had not yet become thoroughly mixed. For short times, a graphical procedure was necessary to determine a mean concentration.

40. Allen, C. M., 1930, The salt velocity method of water measurement. Mechanical Engineering, 52 (n. 4):375-376.

A general description of the use of salt solutions in measuring the discharge and mean velocity of water. A special type of electrode for use in circular pipes is also described.

41. Allen, C. M., 1934, How water flows in a pipe line. Journal of the American Society of Mechanical Engineers, 56 (n. 2):81-84.

A study of brine dispersion in a 40-inch riveted steel penstock utilized 21 pairs of electrodes distributed over the pipe cross section. Brine was injected at various radial positions at stations taken 5, 11.2, 20, and 45 feet upstream from the electrode array. The instrumentation consisted of a bank of ammeters in series with each electrode and a 110 volt A. C. source. Results were qualitative and the data were interpreted in terms of regions of the cross-section affected by the salt solution. Curves were drawn up showing the area over which the brine had spread and these were drawn in such a way as to pass through those only moderately affected and just to touch those affected occasionally.

42. Dryden, H. L., 1939, Turbulence and Diffusion. Industrial and Engineering Chemistry, 31 (n. 4):416-425.

This paper comprises a review of developments in the experimental and theoretical aspects of turbuelnce study in relation to the diffusion process during the years prior to 1939. The author relates Taylor's theory of diffusion by continuous movements, Reynolds description of non-isotropic turbulence, and von Karman's enumeration of the scale

characteristics of non-isotropic turbulence in terms of correlation tensors. Developments in jet mixing and practical means of securing large turbulence to promote rapid mixing are discussed as they apply to continuous processing.

43. Anonymous, 1940, Measurement of velocity in pipe lines by saline injections. Engineering, 150 (n. 3894):179-180.

A discussion of two papers presented at the spring meeting of Worcester, Massachusetts, May 1-3, 1940. Both dealt with the subject of the salt velocity method of gaging, the invention of which is attributed to C. M. Allen. (These papers were by Professor L. J. Hooper and by O. H. Dodkin.)

44. Dodkin, O. H., 1940, Field checks of the salt velocity method. ASME - Trans., 67(n. 8):663-669 (discussion 669-676).

The paper gives the results of some tests made in Brazil in which verification of the reliability of the salt-velocity method of measuring discharge was obtained by cross checks with the method itself, by tests with Gibson pressure-time method, and by volumetric tests. These showed a highly satisfactory agreement even in setups where the testing layout was far from ideal. Unit 5 of the Serra plant of the Sao Paulo Tramway Light and Power Company, Ltd., is a double-over hung impulse turbine of which the nominal rating is 84,000 hp at 680 m (2230 ft) net head and 360 rpm. The injection station consisted of four 2" pop valves set in from the pipe wall 38 per cent of the pipe radius. Elementary electrodes were placed at the side of two of the pop valves to determine the time of the salt solution injection. Each electrode set consisted of two pairs of electrodes at right angles to each other extending across the penstock to within 1/2" of the penstock walls. These electrodes were bowed to have a center spacing 6.5 times that of the electrode ends. In testing the turbine, 24 runs with an average of 5.6 salt shots per run were made. One point in the application of the salt velocity method, and which must be emphasized, where a high degree of accuracy is desired is the timing of the passage of the salt cloud in the waterway. This must be done between sets of electrodes extending across the entire waterway.

45. Hooper, L. J., 1940, Salt-velocity measurements at low velocities in pipes. Transactions of the American Society of Mechanical Engineers, 62 (n. 8):651-661.

Tests were made at the Alden Hydraulic Laboratory to determine the performance of the salt-velocity method at low velocities. Tests were made in a 40-inch pipe, a 12-inch vertical pipe, and a 2-inch pipe. True discharge was obtained by the use of weighing tanks. Even at Reynolds numbers higher than 2500, good mixing was not necessarily obtained. Brine solutions being heavier than water, they tended to settle to the bottom of the pipe at velocities below some "critical velocity." In the vertical pipe, the salt solutions tended to "slip" by the vertically flowing water at velocities below 1.5 ft per sec. For the case of vertically upward flow, the salt solution tended to settle or lag behind the main flow. When the velocities were sufficiently high, this gravitational effect was unimportant. A discussion section includes a report by Fejer and Daily on some visual studies made of salt clouds at various Froude numbers, and photographs are included. E. A. Taylor confirms the critical velocity or critical Froude number concept by referring to some field tests along the Colorado River aqueduct, Metro Water District of Southern California.

46. Mason, Martin A., 1940, Contribution to a study of the Allen salt-velocity method of water measurement. Boston Society of Civil Engineers, 27 (n. 3):207-235.

A physical conception of the salt-velocity method is presented, and theoretical and experimental means of verification of the concept are explained. The paper also includes the description of the experiments run. It was found that the usefulness of the salt-velocity method was limited to cases where there was pronounced turbulence and where the mixing process of the injected solution was mainly affected by the instantaneous velocities rather than by the mean local velocities. The author suspects that the mixing length could be represented by: $M = f(U)AT$; where: M = mixing length, f(U) = turbulence parameter, A = channel area, and T = time.

47. Hess, V. F., 1943, On the use of a radioactive tracer method in water measurement. Trans. of the American Geophysical Union, 24 (pt. 2):587-594.

Laboratory tests were made to determine the feasibility of using radium salts in place of ordinary salt in the salt dilution method of flow measurement as suggested by Joly. Specially designed ionization chambers were used to measure the radioactivity of radium

salts and it was found that the concentrations suggested by Joly (Scientific Proceedings of the Royal Dublin Society 1922, 37:489-491) were too low and that special precautions had to be taken in the use of glassware. No actual flow measurements were made.

48. Kalinske, A. A. and C. L. Pien, 1944, Eddy diffusion. Industrial and Engineering Chemistry, 36 (n. 3):220-223.

Experimental data are reported relating to the diffusion of mass by eddies in turbulent flow. The theory of eddy diffusion developed by G. I. Taylor is confirmed on the basis of experiments on the diffusion of foreign material in a turbulent water stream. A technique for determining the eddy diffusion coefficient for flowing water is developed, and the method is one that can be adapted readily to gases. One of the important items revealed by these studies is that the scale of the turbulence enters directly into the eddy diffusion relationship and it must be measured or estimated if diffusion in turbulent fluids is to be predicted accurately: $D = U/2\ (d\overline{y}^2/dx)$.

49. Karrer, S., D. B. Cowice, and P. L. Betz, 1946, Use of radioactive tracers in measuring condenser water flow. Power Plant Engineering, 50:118-120.

The authors review many of the possible methods for measuring the rate of flow of cooling water through condensers in stream power plants. They report the use of an adaption of the salt method in which a radioactive tracer element is used in the injected solution. A Geiger-counter immersed in a definite volume of the radioactive solution is used for detection. A solution containing radioactive atoms is injected into the cooling water at a known constant rate. During its passage through the circulating pump and the condenser, the solution is thoroughly mixed with the cooling water. Samples collected at the exit side of the condenser after a certain time from the start of injection, show a constant concentration of the radioactive atoms. If the radioactivities of the original solution and of the exit water samples are determined, the rate of flow of cooling water can then be calculated from $Q = qC_1/C_2$. This method was used in the Westport station of the Consolidated Gas Electric Light and Power Co. of Baltimore. The flow rate measured was 549 gals/sec. The results reported were obtained with a relatively small amount of radioactive material, and the method of measurement was not especially efficient because it depended upon the detection of gamma rays by an inefficient gamma-ray counter. The short life isotope of sodium was chosen for use because considerable sodium was already present in the cooling water, and there was thus no question of loss of active material.

50. Tobler, H., 1947, (German), Electrische Salzgehalt-Ermittlung bei Wassermessungen nach dem Salzverduennungs-Verfahren (Electrical determination of salt content in water measurements by the salt dilution method). Schweizerische Bauzeitung, 65 (n. 38):524-525.

The electrical resistance approach is used to measure the salt concentration of river water. A special can was used to add salt solution to the 100 l. water volume until resistance was equal to the salt concentration taken from the river. The details are explained in such a way as to help the reader to avoid many difficulties in applying this method.

51. Winkler, G. and M. H. Wipf, 1947, (German), Wassermessungen nach dem chemischen verfahren (Water flow measurements by the chemical method). Schweizerische Bauzeitung, 65 (n. 31):417-419.

The authors of this article describe the application of the chemical dilution method to determine the discharge rating curve of a free surface flowing concrete pipe. Both the apparatus for chemical injection and that for probing the diluted concentrations are described.

52. Anonymous, 1949, Flow measurement in pipe line. Water Power, 1 (n. 5):199-201.

This paper offers a description of the salt velocity measuring technique as applied in Nostie Bridge Station in North Scotland. The results of this measuring technique were compared with those obtained from a standard sharp crested weir, and it was found that they closely agree.

53. Anonymous, 1949, Hydraulic prime movers - power test codes. Publication by the American Society of Mechanical Engineers, New York, 10018.

Two of the approved methods for discharge measurement are the Allen salt-velocity method and the salt solution (dilution) method. These Test Codes describe briefly these two methods and list a rigorous procedure that should be followed in making these tests.

54. Dumas, H., 1949, (French), Jaugeages de cours d'eau par la méthode chimique (Gagings of streams by the chemical method). International Association for Hydraulic Structures Research Proceedings Third Meeting, Grenoble, IV-6, 6 pages, Sept. 1949.

A perfected chemical method of discharge measurement proposed by the author was applied for the first time to the River Verdon in October 1947. Afterwards, the method was improved by about 100 gagings in 1948 and 1949 on various rivers and in the laboratory, where the practical technique and equipment were further refined. This development was based on previous work and accomplishments in France, Switzerland, Germany, The USA, and Italy. Because the use of NaCℓ always necessitated the measurement of the basic salt content of river water, its use imporved the accuracy of this method. New dosage methods had to be employed to determine accurately the salt concentrations. Moreover, economy in the selection of the type of salt was increased. Sodium bichromate came to be selected in studies on the efficiency of gagings with photo-calorimetric detection technique. Past experience with measurements utilizing this chemical is described in detail.

55. McCarter, R. J., L. F. Stutzman and H. A. Kock, Jr., 1949, Temperature gradients and eddy diffusivities in turbulent fluid flow. Industrial and Engineering Chemistry, 41 (pt. 1):1290-1295.

An outline of turbulent flow theory is presented, and its relation to problems of diffusion are derived and applied in the correlation of data. Equipment and experimental procedure are described for two methods of determining the dimensional value of eddy diffusivity in turbulent gas flow by studies of thermal energy transfer. Experiments were conducted in a vertical 8-inch diameter steel duct with flow velocities ranging from 2 to 7 feet per second; preliminary results obtained indicate ranges of diffusivity for certain conditions of turbulence from which qualitative deduction may be made regarding the factors influencing diffusion and mixing. These methods offer a possibility for a simple and useful tool in the investigation of turbulent flow and transfer problems.

56. Archibald, Ralph S., 1950, Radioactive tracers in flow tests. Boston Society of Civil Engineers, 37:49-116.

This paper starts with a history of flow measurement by chemical means and passes on to a short description of the salt-velocity method in conduits and basins and the salt-dilution method in conduits. But the main purpose of the paper is the presentation of the use of

radioactive tracers in flow measurements and in basin testing. Problems such as health safety, selection of isotopes, instrumentation, laboratory investigations, and short-circuiting in basins, are dealt with. The paper is also accompanied by a theoretical investigation concerning the rapidity of spread of the tracer cloud. The main advantages of the radioactive tracer as expounded in the paper are: (1) radioactive tracers emit distinctive rays, (2) radiation rays are easily identified, (3) minute amounts of radioactive material are required, (4) density effects are absent, (5) radioactive tracers are not affected by physical or chemical changes in solution, and (6) the Geiger tube which is used for radiation detection is placed outside the pipe and thus there is no need of sampling from the pipe.

57. Bouvard, M., 1950, Matériel de jaugeage léger (méthode chimique) [Lightweight stream gauging equipment [chemical method)] La Houille Blanche, 5 (n. 4):466-469.

A description of lightweight equipment for injection and sampling to be used in mountainous areas where back-packing is necessary. The work was done by Electricité de France and the laboratory of Hydraulic Engineering at Grenoble. A number of highly ingenious devices made it possible to carry out precise measurements in mid-winter in mountainous areas where skis were the only possible form of transportation.

58. King, G. W., 1951, Monte Carlo method for solving diffusion problems. Industrial and Engineering Chemistry, 43 (pt. 2):2475.

This paper sets forth the Monte Carlo method as a new means, made available by large scale computing machines, of solving problems in physics and engineering. The author mentions that, with the advent of automatic computing machines, the tendency has been for the differential equation to be put into the form of difference equations and approximate solutions found by numerical methods. However, there is no fundamental reason to pass through the abstraction of the differential equation. Any model of an engineering or physical process involves certain assumptions and idealization which are more or less openly implied in setting up the mathematical equation. By making other simplifications, sometimes less stringent, the solution to be studied can be put directly in the computing machines and a more realistic model obtained than is permissible through the medium of differential or integral equations. Dye diffusion in capillary tubes is used as an example of the method.

59. Thomas, H. A. and R. S. Archibald, 1951, Longitudinal mixing measured by radioactive tracers. ASCE, Proc., 77 (separate n. 84):12p.

To test the use of radioactive tracers in the salt-velocity method in conduits, both field and laboratory experiments were conducted, and both were entirely successful. The laboratory tests were performed on a straight length of 2-in. pipe. The radioactive solution (I-131) was injected quickly into the flow at an upstream point, and points on the curve of the concentration were detected by a Geiger tube placed against the pipe at points along the conduit downstream. Thus, by modification of the flow rate and the distance from the source, the variations in the cloud-spread could be noted in relation to distance and flow rate. Tables are presented illustrating these changes. Results of tracer test on a rectangular primary settling tank of a sewage treatment plant are also presented. The foregoing tests were made at Harvard University and at various places in eastern Massachusetts in connection with an experimental project to investigate the utility of radioactive tracers as a tool of the hydraulician.

60. Dumas, H., 1952-1953, La méthode chimique pour la mesure du débit des cours d'eau (Chemical methods for the gaging of streams). La Houille Blanche, 7 (n. 5):690-701, 8(n. 1):51-57, 8 (n. 3):360-373.

The author thoroughly covers all aspects of this subject: the importance of mixing conditions, analysis of the propogation of a concentration cloud for both instantaneous and prolonged injection, formation of a permanent regime, duration of this permanency, study of accuracy, influence of non-homogeneity, and causes of accidential error. A section on chemicals deals with types of chemicals, quantities and quality, influence of ambient salinity, and methods of analysis. The concluding article deals with the preparation of solutions, injection techniques and devices, sampling techniques and devices, and special precautions for turbid water.

61. Lamm, Ole, 1952, (German), Ueber die Theorie der Selbstdiffusion in fluiden Stoffen und Mischungen (On the theory of self-diffusion in fluid materials and mixtures). Acta Chemica Scandinavica, 6:1331-1341.

"Those cases of self-diffusion are dealt with which seem to point out to the diffusion equations with three-dimensional systems. To these cases belong either the self-diffusion on non-complex gases or liquids in the

presence of forceful components, or the self-diffusion of separated and eventually also of exchangeable pure materials. It is shown that the self-diffusion coefficient depends on roughness magnitude, and the conditions are discussed under which the experimental determination of the roughness coefficients corresponding to these roughness magnitudes (by diffusion measurement) is possible."

62. Maude, A. H., 1952, Constant liquid feed device. Industrial and Engineering Chemistry, 44 (pt. 1):585.

The device described is really a modification of that of Michaeli. The aim in making this modification was to simplify construction and to add flexibility. The greater range of flows and greater accuracy in calibration were made possible by lengthening the controlling element, which is located in a more convenient position than in Michaeli's apparatus. Also, thermostatic bath was added to permit day and night operation under conditions of varying atmospheric temperature. An incidental advantage was an upward flow through the controlling element, because minute amounts of solid would settle before reaching the end of it.

63. Pedersen, S. R., 1952, Liquid-weighing scale controls rate of flow. Electronics, 25:104-106.

A syncho system reacts to a scale unbalance by throttling a valve and hence controlling the flow rate. First, a container filled with liquid is balanced on a special scale. Then, a balance weight is moved by a lead screw and a synchronous motor. As the weight moves in, the scale becomes unbalanced and an error voltage is developed which is amplified and applied as a control voltage to a motorized valve. Next, the valve opens allowing the liquid to flow from the container at a rate dependent upon the rate at which the weight moves in and upon the mass of the weight. An accuracy of one-half per cent within one minute intervals, with an accumulated error of less than one part in 10,000, was obtained.

64. Sons, E., 1952, Die Messung von Fliesszeiten in Wasserlaeufen mit Hilfe von radioaktiven Stoffen (Measurement of travel time in water courses by use of radioactive materials). Wasserwirtschaft, 42 (n. 10):313-317.

Previously the classical methods for measuring the river water travel time, floating devices, salt method, and dye methods have been reviewed and their disadvantages discussed. The River Amseber was used for the experiments with radioactive tracers. The tracer Br^{82}

was employed (halflife 36 hours) as well as NH_4Br in solution (with radioactive Br). A quantity of 20 Millicurie = 0.3 gr. could be detected in 100,000 m^3 of water. The tracer was dissolved in 10 liters of water and in 1 minute introduced into the stream. The travel time, T , was defined from the time of trace introduction to the time when 50 per cent of the tracer passed the point of measurement. The travel velocity is V = L/T , L = distance. The main characteristics of diffused tracer are presented. Velocities were 0.50 - 0.86 m/s. The method is considered useful because it is independent of pollutants in the stream. Details of procedures are given.

65. Frenkiel, F. N., 1953, Turbulent diffusion; Mean concentration distribution in a flow field of homogeneous turbulence. Advances in Applied Mechanics, III:61-107.

The author reviews the statistics of a turbulent field. He then develops the fundamental equation of turbulent diffusion originally worked out by Kampé de Fériet, and discusses its application to large dispersion times, small dispersion times, and dispersion times which cannot be considered either large or small on the Lagrangian time scale of turbulence. Then the theory is applied for several assumed correlation functions. The reverse problem, in which the Lagrangian scale of turbulence is determined from diffusion measurements, is then solved. The author next develops in detail the mean concentration distributions of a point source and an infinite line source. Last, a discussion follows of the the relationship between the differential equations of diffusion and the statistical theory of turbulence.

66. Klinkenberg, A., H. J. Krajenbrink, and H. A. Lauwerier, 1953, Diffusion in a fluid moving at uniform velocity in a tube. Industrial and Engineering Chemistry, 45 (pt. 1):1202-1208.

This study deals with the concentration distributions caused by diffusion in a fluid moving in a cylindrical tube at uniform velocity. In one experimental technique, eddy diffusion constants were derived from concentration patterns produced by a point source of solute on the axis of a packed tube. The concentration distribution was calculated by use of two-sided Laplace integrals. The results are presented in the form of graphs covering the variation of all three variables. The applicability of simplifications (absence of axial diffusion, equality of radial and axial diffusivity, diffusion in infinite space) was examined, and the results should aid in evaluations of data on diffusion, primarily eddy diffusion. In addition, the mechanism of axial eddy diffusion was analyzed and the importance of this phenomenon was stressed. Radial and axial diffusivity are defined and the derivation of the general equations presented.

67. Lin, C. S., R. W. Moulton and G. L. Putnam, 1953, Mass transfer between solid wall and fluid streams. Industrial and Engineering Chemistry, 45 (pt. 1):636-640.

This paper is a theoretical analysis of mass transfer between turbulent fluid streams and the wall. The authors present a method for determining the ratio of the turbulent to molecular mass transfer at the vicinity of the wall and the concentration distribution from the wall to the main body of the fluid.

68. Montens, A., 1953, (German), Die Auswertung von Durchflussmessungen mit radioaktiven Isotopen (Evaluation of flow measurements with radioisotopes). Wasserwirtschaft, 44 (n. 3):63-66.

When radioactive tracers were used in the measurement of residence time for pollutants in settling basins, the residence time was found to be shorter than that computed from the basin volume and inflow rate. Various effects on residence time are discussed. The curves giving the radioactivity of effluent at various times after the injection are bell-shaped with long tails. The interpretation of results is related to these curves, and especially to the properties of their recession parts.

69. Taylor, G. I., 1953, Dispersion of soluble matter in solvent flowing slowly through a tube. Proceedings of the Royal Society of London, Series A, 219:186-203.

When a soluble substance is introduced into a fluid flowing slowly through a small-bore tube, it spreads out under the combined action of molecular diffusion and the variation of velocity over the cross section. In this paper, it is shown analytically that the distribution of concentration produced in this way is centered on a point which moves with the mean speed of flow and is symmetrical about it in spite of the asymmetry of the flow itself. Dispersion along the tube is governed by a virtual coefficient of diffusivity which can be calculated from observed distributions of concentration. Since the analysis in this essay relates the longitudinal diffusivity to the coefficient of molecular diffusion, observations of concentration along a tube provided a new method for measuring diffusion coefficients. The coefficient so obtained was found, with potassium permanganate, to agree with those that were measured in other ways.

70. Truesdale, G. A., 1953, Measurement of sewage flow using radioactive tracers. Journal of the Institution of Municipal Engineers, 80 (n. 4):232-240.

An investigation to determine the time of retention of sewage in settling tanks and in percolating filters using radioactive rubidium and salt as tracers was conducted. Results of experiments using radioactive rubidium as a tracer agreed very closely with those using salt. The long tails of the flow-through curves which could not easily be detected by other means, could be detected using radioactive rubidium.

71. Aastad, Johan and Reinhardt Sognen, 1954, Discharge measurements by means of a salt solution, the relative dilution method. International Union of Geodesy and Geophysics, International Association of Scientific Hydrology, General Assembly of Rome, 3 (n. 38):289-292.

The authors have given a concise description of the salt dilution method which utilizes electrical conductivity equipment for detecting salt concentration. Ample attention is given to the details of electrode pairs, and precautions and details of the discharge calculations.

72. Guntz, A. A., and A. Luxo , 1954, (French), Mesure du débit des ouadis nord-africains par la méthode chimique au bichromate (Discharge measurements of North African wadis by the chemical bichromate method). La Houille Blanche, 9 (special n. B): 747-751.

Experiments were carried out on the chemical gaging method using sodium bichromate (Dodero method), and they were modified to suit the turbid waters which were likely to reduce the bichromate. Colorimetric dosage was used with some alterations and permanganate was added to stabilize the bichromate. Results were satisfactory and confirmed the sensitivity and accuracy of the method in turbid waters.

73. Montens, A., 1954, The use of radioactive isotopes for water flow and velocity measurements. Proceedings of the Second Radioisotopes Conference, Oxford, London:582.

This paper is concerned with the application of radioisotopes to the measurement of water flow in lakes, storage basins, and underground, and it deals with residence time in settling tanks of sewage treatment plants.

74. Taylor, G. I., 1954, The dispersion of matter in turbulent flow through a pipe. Royal Society of London, Series A, 223 (n. 1155): 446-468.

Taylor's classical development relates a virtual coefficient of diffusion to pipe radius and shear velocity. This theory was verified by brine dispersion measurements made in both smooth and rough pipes. It was then applied to the problem of longitudinal turbulent mixing across an interface between two different fluids, one "pushing" the other. The theoretical results showed good agreement with data obtained by Taylor for long pipes.

75. Babbitt, J. D., 1955, Note on the fundamental law of diffusion. Journal of Chemical Physics, 23, (pt. 1):601-602.

The author discusses the general diffusion problem in terms of Fick's Law, the fundamental law of diffusion as elaborated by Maxwell from an elementary hydrodynamics approach and the result of applying kinetic theory to the problem of diffusion. It is specifically pointed out that the Maxwellian derivation only holds for a gas which acts in accordance with Boyle's Law.

76. Garcia, T. B., 1955, Measuring flows by method of mixtures. Chemical Engineering, 62:210.

Volumetric flow rate and specific gravity (rather than actual analysis and concentration) can be used to measure flows provided that the materials mixed are sufficiently similar. The laws of perfect solution can be assumed to hold, and the density of the mixture can be calculated from the known volumes and densities of the components:

$$\frac{1}{S_m} = \frac{W_a}{100S_a} + \frac{W_b}{100S_b}$$

S = specific gravity, W = weight per cent, a = component a, b = component b, m = mixture of a and b .

77. Hull, D. E., and B. A. Fries, 1955, Radioisotopes in petroleum refining, research and analysis. International Conference on Peaceful Uses of Atomic Energy, 15.

This paper is a review of radioactive applications in technology, especially in petroleum refining. Examples of the important uses of radioisotopes described fall into four major groups: (1) measurement and control of liquids and fluidized solids in heavily insulated pipes,

(2) cheaper and faster methods of testing products, (3) tagging of one component of a hydrocarbon mixture for the purpose of analysis and control of the process, and (4) experiments in petroleum refining process.

78. Lamm, O., 1955, The dynamics of the diffusion of fluids in relation to the choice of components. The Journal of Physical Chemistry, 59:1149-1150.

A continuation of earlier papers about the "dynamical theory" of diffusion. The term "dynamical theory" describes the theory in which diffusion is considered a motion of molecules caused by a driving force and modified by frictional forces between the diffusing molecules. By way of the dynamical theory, an attempt is made to provide a background against which practical diffusion problems can be examined, partly in order to distinguish the factors which are general to all diffusion processes and those which are special to a particular system. While the physical theories of diffusion use the simplest possible, most appropriate assumptions regarding the displacement of atoms or molecules, the dynamic theory makes a point of being independent of special assumptions concerning the structure of matter and its mode of transfer.

79. Young, Leslie, C. E. McMillan and R. W. W. Scott, 1955, Salt-velocity flow measurements in a 1-inch diameter pipe. Department of Scientific and Industrial Research, Mechanical Engineering Research Laboratory, Fluid Note No. 33.

"Special recording instruments have been developed for measuring the flow of water using the salt-velocity method. Prior to large scale laboratory and field trials, the apparatus and technique have been tested using a 10-foot length of 1-inch nominal bore pipe over a range of flows corresponding to Reynolds numbers between 4000 and 22,000. An A. C. bridge and amplifier system with linear response was employed, capable of detecting one part of sodium chloride in two million parts of water having a mean conductivity of 33×10^{-6} reciprocal ohms per centimeter. This is more sensitive than most apparatus used hitherto, and gives the advantage that only small quantities of solution of low concentration need to be injected. Despite the high sensitivity and accuracy of the recording instrument, repeated salt velocity measurements gave a scatter of as much as 3 per cent of the mean flow measured by collecting and weighing. Although gage electrodes covering the cross section of the pipe gave more consistent results than point electrodes, the airthmetic mean of flow derived from salt velocity using gage electrodes was about 1.4 per cent

higher than the true flow. It is thought that the scatter and the consistent error may be caused by uncertain mixing at the low Reynolds numbers involved. Similar tests at higher Reynolds numbers will be made to verify this."

80. Aris, R., 1956, On the dispersion of a solute in fluid flowing through a tube. Royal Society of London, Proceedings, Ser. A, 235 (n. 1200):67-77.

The author describes the distribution of solute in terms of its moments in the direction of flow. The rate of growth of the variance is shown to be proportional to the sum of the molecular diffusion coefficient D_1 and the Taylor diffusion coefficient Ka^2U^2/D_1 where U is the mean velocity and a is some characteristic dimension of the tube. An expression of K is given for the most general case, and it is shown that a finite distribution of solute tends to become normally distributed.

81. Batchelor, G. K., 1956, Diffusion in a fluid in turbulent motion. Applied Mechanics Reviews, 9 (n. 3):89-91.

A general survey of the problem of turbulent diffusion and its various facets is presented in descriptive form, i.e., non-analytical form. In turbulent flow there are three separate effects to contend with. There is a convection of marked fluid along the streamlines of the mean flow convection due to turbulent fluctuations in fluid velocity and also to molecular diffusion which cannot be neglected when the concentration gradients become large. The author goes on to discuss particular features of diffusion in a field of homogeneous turbulence, shear flow with partial homogeneity and diffusion from a maintained source in shear flow. In particular, Batchelor discusses the time dependency of diffusion for both homogeneous and partially homogeneous flow fields. He emphasizes the fact that the total diffusion is not necessarily a linear combination of the effects of molecular diffusion and turbulent diffusion taken separately. Molecular diffusion is still significant even in the limit of extremely large Reynolds numbers. The concluding section is devoted to recent advances in the diffusion of marked fluid elements relative to each other. Fifteen references are cited.

82. Beatty, K. O., J. K. Ferrell and F. M. Richardson, 1956, Radioisotopes in the study of fluid dynamics. Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, 8-20 August 1955. Applications of Radioactive Isotopes and Fission Products in Research and Industry, United Nations, New York 15:194-198.

This paper includes a review of the several uses of radioactive tracers in fluid flow and considers some possible future applications. Radioactive tracers are reportedly used in the determination of the path of a fluid body, the average velocity of fluid flow, and the relative motion of various parts of a fluid stream. Tracer displacement technique is described as the study of the rate and manner of displacement of a radioactive material with a non-radioactive material. Na^{24} was used as tracer by the authors. The results of experiments conducted both in laminar and turbulent flow are reported. Unfortunately, the molecular diffusivity of solute molecules has been a drawback in the application of the tracer displacement technique. It is anticipated by the authors that radioactive tracers will have more application in the field of fluid dynamics, particularly in mass transport or dispersion of a dissolved material in a flowing fluid, in the years to come.

83. Putnam, J. L. and S. Jefferson, 1956, Application of Radioisotopes to leakage and hydraulic problems. Proceedings of U. N. International Conference on Peaceful Uses of Atomic Energy, 15:147-150.

Three methods of detecting leaking areas (which do not exceed 5 km) in a pipe line, are described in the paper. Methods for localizing small and high rates of leakage in long mains are also presented. Detection of leakage in much longer oil pipe lines was made feasible by the successful release of two Geiger counters into the pipe line in the experiments. In the case of a large diameter pipe, the radioactive dilution method was recommended, and techniques for the detection of interfaces in pipe-lines and siltation problems were set forth.

84. Redding, T. H., 1956, Achieving a constant rate of flow; Theory of the floating syphon. Engineering, 181:297-302.

A device which makes use of a floating syphon for the delivery of a constant rate of flow was devised by the author. Stability of the float was ensured by the use of a guide rod and by a ring weight which was attached below the float. The rate of discharge was given by

$$Q = \frac{\pi D^2}{4} \cdot \frac{2gH}{1 + K_1 + K_2 + K_3}$$

where Q = volumetric flow rate, D = diameter of tube, H = syphon-head, K_1 = entrance loss factor, K_2 = line loss factor, and K_3 = exit loss factor. Different flow rates corresponding to different syphon heads could be achieved by moving the syphon up or down with respect to the float.

85. Southgate, B. A., 1957, Apparatus for dosing a solution of a radioactive tracer at a constant mean rate. Water Pollution Research Laboratory, London, H. M. Stationary Office:94-95.

Equipment for the delivery of radioactive solution at a constant rate is described. A free piston within a cylinder connected to two electromagnetic valves constituted the control mechanism. A master clockwork contractor gave impulses at 0.5-second intervals to a series of electromagnetic scales-of-two which in turn controlled the electromagnetic valves. The rate of delivery was observed to vary ± 0.3 per cent around the mean.

86. Batchelor, G. K., 1957, Diffusion in free turbulent shear flows. Journal of Fluid Mechanics, 3 (p. 1):67-80.

This paper is concerned with some statistical properties of the displacement of a marked fluid particle released from a given position in a turbulent shear flow, and in particular, with its dispersion about the mean position after a long time. It is known that the dispersion takes a simple asymptotic form when the particle velocity is a stationary radom function of time, and that analagous results are obtainable when the particle velocity can be transformed into a stationary random function by suitable stretching of the velocity and time scales. The basic hypothesis of this paper is that, in steady free turbulent shear flows which are generated at a point and which have a similar structure at different stations downstream, the velocity of a fluid particle also exhibits a corresponding Lagrangian similarity and can therefore be transformed to a stationary random function. The velocity and time scales characterizing the motion of a fluid particle at time t after release at the origin were determined in terms of the powers with which the Eulerian length and velocity scales of the turbulence vary with distance x from the origin. Time scales have the same dependence on t for all jets, wakes, and mixing layers (and also for decaying homogeneous turbulence) which possess the usual kind of Eulerian similarity. The dispersion of a particle in the longitudinal or mean-flow direction (and likewise in the lateral direction in cases of two-dimensional mean flow) was found to vary with t in such a way as to be proportional to the thickness of the shear layer at the mean position of

the particle. The way in which the maximum value of the mean concentration of marked fluid falls off with t (for release of a single particle) or with x (for continuous release) was also worked out.

87. Bonnin, J., H. Dumas and R. Lievre, 1957, (French), Etude de la diffusion saline en regime permanent dans conduite circulaire (Study of salt diffusion in a permanent regime in a circular conduit). International Association for Hydraulic Research, Transactions, 2 (paper D9):1-23.

Brine solution was injected into a pipe 250 mm. in diameter and 42 meters long. The spatial distribution of the saline was then studied in terms of injection through a nozzle at the center line or at the wall of the pipe. The effect of brine density and the wake produced by the injection nozzle were examined separately. The development of these distributions was calculated on the basis of Reynolds analogy, and this helped to explain some peculiarities of the experimental results.

88. Kudsk-Jorgensen, B., 1957, Calculation of time-concentration curves in a stationary, laminar liquid flow through a circular-cylindrical tube. Civil Engineering and Building Construction Series, 4(n. 6).

In this paper, two equations based upon velocity distribution in a laminar flow through a tube are set up. They are proposed for the calculation of time, and concentration curves for any cross-section of a tube into one end of which a dye solution has been introduced within a short time and on the assumption of instantaneous and complete mixing. The possibility of using this theory on a branched system is discussed, and equations for approximate calculations are worked out. For the sake of demonstration, the equations are applied to calculating time concentration curves from the experimentally determined distribution of a dye solution in the blood circulatory system.

89. Levenspiel, O. and W. K. Smith, 1957, Notes on the diffusion-type model for the longitudinal mixing of fluids in flow. Chemical Engineering Science, 6:227-233.

The longitudinal mixing of fluids in flow can sometimes be characterized by a single parameter, D , the "longitudinal dispersion coefficient" which is analagous to, and has the same units as, the coefficient of molecular diffusion. Reported in this paper, the results of a study of this model show that a dimensionless parameter, the Peclet number, can be used as the similarity criterion for longitudinal mixing. Also, it is pointed out that the obvious and direct method of calculating the

mean velocity of flow by injecting a tracer into the fluid stream at one point and measuring its maximum concentration at a given point downstream may, in some cases, lead to an appreciable error even if the diffusion type model is applicable. Methods are shown for evaluating D from experimental measurements; in addition, examples are worked out, and the conditions necessary for applicability of the model are discussed.

90. Moser, Herbert and Ferdinand Neumaier, 1957, (German), Die Anwendung radioaktives Isotopen in der Hydrologie (The application of radioactive isotopes in hydrology). Atomkernenergie (Germany), 2 (n. 1) January:26-28.

The flow measurements with radioactive isotopes in canals without outflow or inflow, or in those with inflow or outflow, are discussed. By measurement of the concentration of radioactive isotopes along a canal or a river (in the case of experiments carried out by authors, the radioactive iod was used), the water inflow or outflow along these courses can be determined. The techniques of various field measurements are described.

91. Shumilovskii, N. N., YU. V. Gushchin and M. I. Tolokonnikov, 1957, (Russian), Primenenie radioaktivnyklh izlucheniy dlya avtomaticheskogo kontrolya raskhoda zhidkosti v zakrytykh truboprovodakh (The application of radioisotopes to the automatic control of liquid flow in closed pipe lines). Mashinostroenie i priborostroenie, Trudy Vsesoyuznoy nauchno-tekhnicheskoy konferentsii po primeneniyu radioaktivnykh i stabil'nykh izotopov i izlucheniy v narodnom khozyaystve i nauke, 2d, 1957, Moscow, Izdatel'stvo Akademii Nauk SSSR, 1957:267-270.

The method of flow measurement recounted in this paper consists in utilizing the mechanical undulation of radioactive emissions. Actually, in the flow is the sensing equipment consisting of a rotating helic with one or several blades with the radioactive isotope C_o but out of contact with the flowing liquid and the colimator. A protective screen is put between the source of radiation and the sensing instrument in order to weaken the intensity of radioactive emissions (use of the relatively inactive S_n^{113}, ^{123}, C_s^{137}, and E_u^{159} may also be made. Each turning of the helic giving the package of gamma-quanta are rated by the colimator with the liquid discharge proportional to the revolutions. Both the theory underlying the method and the details of liquid flow measurements are described in detail.

92. Weeda, W., 1957, (Dutch), De praktische uitvoering van enkele stromingsmetingen met radioactieve stoffen (Practical performance in some flow measurements by radioactive materials). De Ingenieur, 69 (n. 9. 0.), Technische Wetenschappelijk Onderzoek, 2:0.23-0.29.

The following three measurements of radioactive materials in water flows are described in this article:

(1) The measurement of a volume rate in a water circuit of about 450 cum/h. About 10 mc of Na^{24}, mixed in a volume of 30 liters was added to a continuous stream, and rate measurements were then accomplished. These were arrived at by: (a) determination of the time taken by the front and back of the radioactive "cylinder" moving in the pipeline flowing from one fixed point to the other, and (b) by taking of samples from the injection liquid and from the radioactive liquid in the circuit in order to find the volume rate in the circuit (a total of the ratios of the specific activities of these samples together with the injection rate). The accuracy of both methods is in the order of several per cent.

(2) The measurement of the retention time in a pond with a surface area about 10,000 sq. m, depth 2m. About 100 mc Na^{24} was used, and detection was carried out by means of Geiger tubes.

(3) The continuous measurement of the density of a suspension flowing through a pipeline. To gage the degree of absorption, a beam of gamma rays of Ir^{192} was sent diametrically through the cross section of the pipeline, and here also the detector was a Geiger tube.

93. Young, L. and G. Wilson, 1957, Developments in salt-velocity flow measurement. Fluids Report No. 60, Mechanical Engineering Research Laboratory, Department of Scientific and Industrial Research, United Kingdom.

An extensive series of laboratory experiments supplemented by field tests were made on the salt-velocity method of flow measurement and are reported in this paper. Comparative flow measurements were taken by a standard weighbridge in the laboratory and by current meters in the field. (The field tests showed similar accuracy for the standard bridge measurements.) The laboratory experiments showed that, subject to certain limitations, the apparatus used gave results with 95 per cent confidence limits of error of ± 1 per cent.

94. Hull, D. E., 1958, Total-count technique in the refinery. Industrial and Engineering Chemistry, 50 (n. 2):199-200.

This paper describes a summary of the principles behind the total-count method and its application to refinery industry. Cesium-134

chloride was used as the tracer in sodium chloride for measuring condenser rates. Tests were also conducted to compare the results of the total-count method with the two-point velocity measurement method. According to the author, leak rate determinations and entrainment problems in distillation could also be investigated by this method. The sources of error involved were those due to statistical errors of counting and experimental errors due to the mounting of pipes and retention of tracer in 1-pint bottle. Moreover, a good portion of error was due to assumptions, sensitivity of counters, and corrosion or deposition on pipe walls.

95. Hull, D. E., 1958, The total count technique; a new principle in flow measurement. International Journal of Applied Radiation and Isotope, 4:1-15.

"This paper describes a new principle for measuring flow in all kinds of streams. First, a known quantity of radio tracer A is mixed in a flowing stream. Then, a counter fixed in or near the stream some distance downstream registers a total of N counts from the tracer while it passes. The flow rate Q is given by the relation $Q = AF/N$. The constant factor F is determined by laboratory calibration of the counter. This simple formula is a completely general expression for the absolute determination of flow rate of liquids and gases in any kind and size of conduit. It appears to hold true without modification over an extremely wide range. The total count above and below the junction of confluent streams measures the flow at each point. The total count in a divergent stream, no matter what fraction of the traced stream it carries, depends only on the flow of the whole stream. These principles can be applied to measuring the flow of water and oil in pipes in operating industrial plants. Also, water flow can be measured in open channels and natural streams. Other applications of the total-count method are to the measurement of leaks in condensers and heat exchanges and of entrainment in distillation columns."

96. Levenspiel, O., 1958, Longitudinal mixing of fluids flowing in circular pipes. Industrial and Engineering Chemistry, 50:343-346.

The problem of fluid self-mixing in vessels is discussed in relation to the study of Danckwerts who considered it in the light of the distribution of, or spread in, the residence time of the fluid in the equipment used. Danckwerts summarized experimental techniques for the measurement of the distribution of residence times. These methods all involve introducing tracer material into the incoming fluid stream and measuring its concentration in the outgoing fluid stream, but they differ in the way the tracer is introduced -- whether continuously or in amounts

varying sinusoidally with time or in any cyclic manner. It may also be introduced continuously in concentration C_o after an initial time, before which no tracer is introduced at all. Finally, it may be injected in an instantaneous slug. Typical tracer input and output concentration time are shown in diagrams illustrating these methods of tracer introduction. The application of diffusion to the three types of curves is discussed. The paper also introduces a table summarizing experimental data for diffusion in pipes, a design chart incorporating data from the literature that can be applied to pipeline studies, and the design of chemical reactors testing the amount of contaminated fluid at the outlet of a pipe.

97. Levenspiel, O., 1958, How much mixing occurs in a pipe? Petroleum Refiner, March 1958, 37:191-194.

Charts are presented in this paper for the prediction of the zone of contamination as related to dispersion number and pipe dimensions. Turbulent flow and streamline flow are dealt with separately, and illustrative problems are solved which exemplify the use of the charts. Product contamination, as the author puts it, is due to "...the axial mixing of fluids and as such its extent can be predicted theoretically considering velocity profiles, molecular transfer and eddy transport of the material in flow."

98. Parker, Frank L., 1958, Radioactive tracers in hydrologic studies. Transactions, American Geophysical Union, 39(n. 3):434-439.

"The use of radioactive tracers to study phenomena in hydrology that have not previously been easily amenable to investigation is proceeding at a rapid pace. A group of experiments was carried out in lakes and reservoirs in Massachusetts to determine eddy diffusion coefficients. The average eddy diffusion coefficient divided by the radius of the eddy was found to be 0.09 ft/sec. A group of experiments to determine the average velocity of streams and the dilution in streams by use of radioactive tracers was then performed. The diffusion coefficients found in the test of the streams were compared with theoretical diffusion coefficients of G. I. Taylor for straight pipes and found to be larger due to the increased dispersion caused by bends and obstructions in the streams. A mathematical formulation for general use in determing dilution and dispersion in rivers and streams by radioactive tracers was established. A correction is made for the adsorption and decay of the isotope depending upon its chemical and nuclear properties. Work is under way at Harvard University to delineate further the adsorption coefficients of important isotopes under various conditions leading to a better determination of the eddy diffusion coefficient."

99. Simpson, E. S., W. A. Beetem and F. H. Ruggles, 1958, Radiotracer experiments in the Mohawk River, New York, to study sewage path and dilution. Transactions, American Geophysical Union, 39 (n. 3):427-433.

"Sewage from the Knolls Atomic Power Laboratory near Schenectady, N. Y., was dosed with 4.53 curies of P^{32} prior to discharge into the Mohawk River. Its pattern of diffusion was measured in the river with immersible GM-tubes and by sampling. The initial path of sewage was strongly influenced by differences in density between sewage and river due to temperature. During warm months, relatively cold sewage moved on the river bottom perpendicularly to river current. For at least the first 800 ft of travel, the maximum sewage concentration decreased logarithmically with distance from outfall. The term "half-distance" (here about 100 ft) is proposed to describe the concentration change. During cold months, sewage rose to the river surface and at times was moved upstream by wind. However, when the river temperature was near freezing, the sewage first rose and then sank as the temperature of the sewage-river mixture approached 39^0 F."

100. Spencer, E. A. and J. S. Tudhope, 1958, A literature survey of the salt-dilution method of flow measurement. Journal of Institution of Water Engineers, 12 (n. 2):127-138.

"There are a number of methods available for large-scale water flow measurement and a comparative study is being made of these at the Mechanical Engineering Laboratory, East Kilbride. In the salt-dilution method, a chemical solution ofknown strength is injected at a constant rate into the natural water, and samples taken downstream are then analyzed to determine the amount of dilution that has taken place. From this, the main rate of flow may be determined. A survey was made of the published work on this technique of gaging flow, and it was noted that recent tests on stream gaging in France have demonstrated that certain chemical salts, for instance sodium dichromate, have definite advantages over the generally accepted brine solution."

101. André, H., 1959, (French), L'amélioration des mesures des débits dans les aménagements hydroélectriques; un cas concret: le bassin de la Romanche (The improvement of discharge measurements in hydroelectric plants; a concrete case: the basin of the Romanche River). La Houille Blanche, 14 (special no. B):923-933.

This paper includes a description of the establishment or re-establishment and calibration of five gaging stations in the Romanche basin and also a section on the calibration of Chambon dam spillway gates by the chemical method.

102. Batchelor, G. K., I. D. Howells and A. A. Townsend, 1959, Small scale variation of convected quantitites like temperature in turbulent fluid. Journal of Fluid Mechanics, 5(pt. 1):113-139.

When some external agency imposes on a fluid large-scale variations of some dynamically passive, conserved scalar quantity, θ, like temperature or concentration of solute, turbulent motion of the fluid generates small-scale variations of θ. This paper describes a theoretical investigation of the form of the spectrum of θ at large wave-numbers, taking into account the two effects of convection (with fluid and molecular diffusion and with diffusivity K.) Therefore, Kolmogoroff type hypotheses were assumed to apply to small scale variations of θ. Also, the authors review previous contributions to the problem. Finally, the relation between this work and Townsend's model of the small-scale variations of vorticity in a turbulent fluid is discussed.

103. Cameron, J. F., P. F. Berry and F. Taylor, 1959, A radioactive method of measuring low water-flow rates. British Chemical Engineering, 4 (n. 2):76-77.

A prototype of an instrument for the purpose of measuring low flow rates at high pressures was made. The instrument was to detect the position of a radioactive float by means of a scintillation counter almost 10 times more sensitive to cobalt-60 as a Geiger counter or an ionization chamber detector. The count-rate versus float height curve depended on the distance of detector from the axis of the instrument. Typical rating curves for several chosen distances were plotted and are included in the report.

104. Gupta, H. C., 1959, Diffusion by continuous movements. Journal of Mathematics and Physics, 38 (n. 1):36-41.

An attempt is made in this essay to treat diffusion through continuous movements by solving the infinitesimal transition equations using Fourier and Laplace transforms. For one-dimensional diffusion, the method is easy but it becomes increasingly complex when the number of velocities is increased. The case of two velocities is treated with its possible ramifications, namely, diffusion with emigration, continuous supply at the origin, and a time-dependent rate of transition.

105. Hermant, C., 1959, (French), L'application de la mesure des débits par la méthode de dilution comparée à la determination du rendement des turbines (Application of the method of measuring discharge by dilutions compared with determination of the efficiency of turbines). La Houille Blanche, 14 (n. 6):808-819.

Very precise experimental work was necessary to obtain accuracies of the order of 1 per cent. A special colorimeter for sodium bichromate detection and a special positive displacement pump were developed. The basic principles of the method as well as the sources of error, the experimental results, and some applications of the method, are discussed.

106. Hull, D. E., M. Macomber and J. H. Easthagen, 1959, Flow measurement by radiotracer. Sewage and Industrial Wastes, January:45-52.

This paper is a description of the application of the total-count method to the measurement of industrial wastes. Three tests were conducted in an oil-water separator effluent stream in an oil refinery in California. The tests proved that the position of the counter in the channel was immaterial. In order to eliminate the error caused by using a calibration factor for an infinite volume, the sample-bucket technique, which guaranteed the use of the same geometical configuration both in the field and laboratory, was developed. The technique was found quite useful in sewers where there was rarely enough discharge to surround the counter. The authors state that the total-count method can be used where meters have defaulted or have never been installed.

107. Orlob, G. T., 1959, Eddy diffusion in homogeneous turbulence. American Society of Civil Engineers Proceedings, 85, n HY9 (n. 2150):75-101.

Taylor's theory of diffusion by continuous movements and Einstein's equation of diffusion were applied to eddy diffusion of particles in a two dimensional field of homogeneous turbulence produced by a broad shallow channel with extreme bottom roughness. A simple method of determining the Lagrangian eddy size, eddy diffusivity, turbulence intensity, and mixing length was devised. Application of this technique provided experimental verification of the Kolmagoroff similarity principle which relates eddy diffusion, the rate of energy dissipation, and the Lagrangian eddy scale.

108. Rhode, Herbert von, 1959, (German), Belueftundsversuche und Durchflussmessungen mit radioaktiven Isotopen auf der Klaeranlage Wickede des Ruhrverbandes (Aeration experiments and flow tests with radioactive tracers at the Wickede Sewage Treatment Plant of the Ruhrverband). GWF, Das Gas- und Wasserfach, 100 (n. 4), Jan. 23:77-84.

The second part of this paper deals with the measurement of flow passage through waste settling basins by use of radioactive isotopes. By this method, the velocities of fluid in various parts of waste settling basins was determined.

109. Shumilovskiy, N. N., Yu V. Guschin and M. I. Tolokonnikov, 1959, (Russian), Primenenie radioaktivnykh izlucheniy dlya avtomaticheskogo kontrolya raskhoda zhidkosti v zakrytykh truboprovodakh (Application of radioactive emissions for the automatic control of fluid discharge in closed conduits). Minister of Higher Education, USSR, Transactions of Higher Education Institutions, Instrumentation, (n. 1):132-138, Published by Leningrad Institute of Precise Mechanics and Optics (No. 71822).

A new apparatus, using a radioactive source of material, for continuous recording of flow rates of various fluids (under very adverse conditions) is presented in this paper. For the method described, a propeller was tagged with radioactive material (0-60 or others), but the fluid did not come into contact with the radioactive material, though the propeller was turned by the fluid inside a pipe. The emission of gamma rays was measured outside the pipe after it had been transformed into electrical signals. The principal schematic of this apparatus is given. Various functional relationships of variables are discussed, and results of the measurements in the experiments are shown. Also, the range of errors as function of flow rates (up to 2000 lit/sec) is demonstrated. Finally, it is noted that this new instrument makes possible a continuous recording of changing flows of various fluids.

110. André, Henri, 1960, (French), Méthode chimique de dilution. Procédé par integration (Chemical method of flow gaging. The integration method). La Houille Blanche, No. B, Dec:163-173.

The principles and basic assumption of chemical flow measurement are reviewed. Operational procedures in the field, such as injection and sample taking, and procedures in the laboratory are discussed. In experiments, bichromate salt was used as the chemical agent. The results obtained were examined with stress on the investigations into

the inherent measurement errors of the method and on comparisons with results obtained at the same time by other methods. The possibilities, advantages, and drawbacks of the methods are discussed, and potential improvements are suggested.

111. Carpenter, James H., 1960, Tracer for circulation and mixing in natural waters. Public Works, 91:110-112.

The use of a fluorometer for the study of time and space distribution of materials is presented in this paper. Rhodamine B was chosen by the author as the tracer material because it is non-toxic, is stable, soluble, and commercially available. It is also easily detected by its fluorescence. The effects of temperature, acidity of solution, and light on the properties of the fluorescent solution are discussed. An example of the application of the fluorometric technique which is presented in this paper is the flushing rate determination of Baltimore Harbor.

112. Clayton, G., 1960, Precise tracer measurements of liquid and gas flows. Nucleonics, U. S. A., 18 (n. 7):96-100.

Measurements of liquid and gas flows were carried out at the National Engineering Laboratory (England) using radioactive tracers in both the Isotope Dilution Method and Pulse Velocity Method. The system used for experimentation was a 700 ft long, 20 in. diameter pipeline, in which there could be flow rates as high as 20 cfs. In the Isotope Dilution Method, Na^{24} was used as a tracer because it is soluble and stable in liquids. A piston driven through an accurately ground cylinder by a synchronous meter constituted the injection pump. Samples were taken at 110 and 220 diameters downstream from the injection point where complete lateral mixing was obtained. Accurate information concerning the internal dimensions of the test pipe was required for the Pulse Velocity Method. The injection of a small amount of radioactive material was a rapid, radial one with enough force to spread the tracer across the section. For the rapid injection, a spring-operated injector was used. Timing was determined by consideration of the centroid of the pulse. The results were compared to those obtained from direct weighing and the error did not exceed 0.44 per cent.

113. Flint, D. L., H. Kadar and T. J. Hanratty, 1960, Point source turbulent diffusion in a pipe. American Institute of Chemical Engineers, Journal 6 (n. 2):325-331.

Turbulent diffusion from a small source located in the center of a 3-in. pipe was studied. Hydrogen and carbon dioxide were mixed in air, and potassium chloride solution was mixed in water. The eddy

diffusion coefficients calculated form the data were correlated by plotting $\epsilon/2aU_c$ versus N_{Re}, a coefficient with a the pipe radius and U_c the time average fluid velocity at the center of the pipe. Disagreement of the results of this study with the results given in the literature are discussed. Finally, the results could not be used for determining the form of the correlation coefficient because of inaccuracies in the measurements for small diffusion times.

114. Hull, D. E., 1960, Tracing of water flow by means of radioactive isotopes and scintillation counters. International Jounral of Applied Radioisotopes, 7. 3:260.

This paper includes a comparison of the use of Geiger tubes and of scintillation counters in the tracing of water flow. Mr. Hull prefers the use of Geiger tubes in parallel to the use of scintillation counter whenever the amount of sample is unlimited. He asserts that the advantage of Geiger tubes is their quantitative equivalence; the change of sensitivity arising from replacing one tube by another in a fixed-voltage circuit is not more than "1" per cent, while a similar exchange of scintillation probes results in a change of sensitivity up to 50 per cent. The paper includes a comparative table of properties of scintillation and Geiger counters.

115. Hull, D. E., B. A. Fries, R. J. Dupzyk and D. J. Lamoree, 1960, Isotope engineering at large flow rates. Transaction of American Nuclear Society, Session 23:453-454.

A summary of the total-sample method which is a variation of the total-count method, is given in this paper. The total-count method became uneconomical as soon as large volumes of flow were involved. Therefore, a method called the total-sample method was devised which was basically a continuous smapling from the tracered stream. Counting was performed at a later time. The rate of flow was given by $Q = AF/RT$, where R is the counting rate, F is the counting sensitivity, A is the quantity of injected tracer, and t is the collection time. The advantage of the new technique was the reduction of the required tracer for a certain accuracy by the ratio N/Rt. The method was first applied in an ammonia synthesis plant for the purpose of determining the trap efficiency of CO_2.

116. Hutton, Stanley Peerman and E. A. Spencer, 1960, Gauging water flow by the salt-dilution method. Proceedings of Institution of Civil Engineers, 16:395-418.

"The salt-dilution method, in which a chemical is injected into the mair stream at a known rate and samples are taken downstream where mixing is complete, has been studied at the National Engineering Labcratory in 1-, 6-, and 20-in. dia. pipelines where the absolute flow rate was accurately known. Field tests in pipelines up to 76 in. dia. have also been made at two hydro-electric schemes in Scotland and one in Switzerland, where the salt-dilution measurements could be compared with the flow recorded by current-meters. Sodium dichromate was used for most of the test; its concentration was measured by volumetric and also colorimetric methods of analysis. In addition, laboratory tests were carried out (in collaboration with the Atomic Energy Research Estaolishment (A. E. R. E., Harwell), using radioactive sodium bicarbonate. For the field tests, injection apparatus was developed for measuring flow rates up to 400 cusecs, using volumetric analysis for determining concentration. By reducing the injection period to abou: 4 min. and by employing dilution ratios up to 60,000, it was possible to use only small quantities of chemical. When injecting and sampling on the pipe axis, a straight length of about 90 pipe diameters was sufficient to obtain adequate mixing. With improved equipment and techniques, salt-dilution results were within 2 percent of both absolute measurements in the laboratory and the flow measured by current-meters in the field. A greatly improved analytical technique resulted from the use of raw water from the pipeline to prepare the standard solutions needed for determining the final concentration, the preparation being carried out at the time of the test. This comparative technique is essential in all cases where chemical changes with time are likely to occur, and it is also strongly recommended for general practice."

117. Lange, W. and S. Menzel, 1960, (German), Ueber die Messung und Regelung von Stroemungs geschwindigkeiten in geschlossenen Rohrleitungen mit Hilfe radioactiver Isotope (On the measurement and regulation of flow velocities in closed conduits by using radioactive isotopes). Die Technik, 15 Year, 4 April:277-281.

The method consists of introducing into conduits a radioactive liquid which does not mix with the flowing water, or a radioactive floating object, and then measuring the flow velocities. The time of passage between two points gives the velocity. The measuring of the deflection angle of a vertical plate in the pipe deflected by the velocity, by using the radioactive material,is also discussed. In addition, the measurement of the number of revolutions of current meters by use of

radioactive material is detailed. Then, the influence of basic magnitudes, such as the time constant of apparatus, the relationships of the impulse density, the absolute value of impulse density, and the effect of transition from one impulse density to the other is set forth. Finally, the selection of isotopes and their counting apparatuses and the results of experiments are described at the end of the article.

118. Lee, J. C., 1960, Tracer measurements on a large diameter pipe. Chemical Engineering Science, 12 (n. 3):191-197.

A simple tracer experiment carried out on a large underground water pipe enabled the following to be determined: the volumetric rate of flow, the linear velocity in the pipe, and the amount of silt settled out in the pipe. The author describes this experiment, and the method by which the longitudinal mixing or dispersion coefficient was determined.

119. Lin, C. C., 1960, On a theory of dispersion by continuous movements. National Academy of Sciences - Proc., 46 (n. 4, 8):566-70, 1147-1150.

This paper presents a derivation of Richardson's law of dispersion by applying the general approach of Taylor's theory of diffusion by continuous movements. When dispersion from a point source is to be considered, this derivation is claimed to be valid even when not all the requirements of Kolmogoroff's theory are fulfilled. The analysis gives rise to Lagrangian parameter B which is of the same dimension as the rate of energy dissipation ϵ .

120. Mickelsen, W. R., 1960, Measurements of the effect of molecular diffusivity in turbulent diffusion. Journal of Fluid Mechanics, 7(pt. 3):397-400.

Townsend (1954) has shown that turbulent vorticity may rotate and strain a diffusion wake, thereby increasing the contribution of molecular diffusion to the total mean dispersion over short diffusion times. To test whether any such effect occurs at longer diffusion times, the writer measured the lateral dispersion of both helium and of carbon dioxide in air downstream from a continuous point source in the turbulence produced by a grid in a wind tunnel. The data show that for long diffusion times, accelerated molecular diffusion is negligible, so that molecular diffusion makes only an independent contribution to the total dispersion.

121. Mikhail, Sami, 1960 Mixing of coaxial streams inside a closed conduit. Journal of Mechanical Engineering Science, 2 (n. 1):59-68.

Flow inside a closed conduit is assumed to be divided into three axial regions: the first with a core of uniform velocity along the outer surface of which mixing occurs; the second with no central core and with the diameter of the primary stream equal to that of the mixing chamber; and a third with the primary stream completely filling the conduit but with the velocity profile not yet stabilized to the logarithmic form. The integral form of the momentum equations were applied by the author to each region, and the velocity profile was assumed to be representable by a cosine function. The resulting differential equations were then linearized by his assuming that the velocities of the primary (core) and secondary streams remain constant with axial distance, and that, despite changes in boundary layer thickness, the radius of the bounding conduit remains constant. The shear stress was written according to Prandtl, and the integrated differential equations were solved by matching solutions at the boundaries of the different regions. The solutions agreed qualitatively with data obtained from an air jet mixing study.

122. Ramdohr, Harold, 1960,(German), Stroemungsuntersuchungen mit radioaktiven Nukliden (Flow investigation by radioactive nuclei). GWF, Das Gas - und Wasserfach, Year 101, 34:843-855.

The application of radioactive nuclei for flow investigation is discussed for the following cases: (a) Measurement of flow velocity for a volume element, by the measuring of the time Δt of passage of nuclei between two points at distance s, in $\overline{V} = s/\Delta t$, with several variations possible in the application of this technique; (b) Determination of discharge in $Q = \overline{V}A$, by obtaining $\overline{V}$ and A by measuring $\overline{V}$ as under (a), and A = area of the conduit; and (c) Measurement of the mixing of any material added to the liquid flow, with area A known but changing all along, by the measuring of the diffusion of a given quantity of nuclei.

123. Saffman, P. G., 1960, On the effect of molecular diffusivity in turbulent diffusion. Journal of Fluid Mechanics. 8(pt. 2):273-283.

In this article, it is shown that the dispersion of a substance with molecular diffusivity K, in a stationary, homogeneous, turbulent velocity field can be formulated in terms of a substance auto-correlation function. This formula is a generalization of the well-known Lagrangian correlation between the velocity of a fluid particle at different times. According to the author, the interaction between molecular diffusion and turbulent motion reduces dispersion from the value it would have if the

processes of molecular diffusion were independent and additive. In fact, the conflict is resolved between the results obtained in this paper and previous results which implied that the interaction increases dispersion. The ratio of the contributions to the dispersion from the interaction term and from the turbulent diffusion terms is obtained for comparatively large times by the use of intuitive arguments, and it is found to be inversely proportional to the Prandtl number and a Reynolds number of the turbulence.

124. Soo, S. L., and J. A. Regalbuto, 1960, Concentration distribution in two-phase pipe flow. Canadian Journal of Chemical Engineering, 38 (n. 5):160-166.

In this essay, the diffusion equation for steady state diffusion of solic matter due to stream diffusivity is solved in the form: $C = C_o J_o (r\sqrt{f/D_u})$. Measurement of concentration distribution was made along a vertical diameter of a 3-inch pipe. Air was the flowing fluid and the dispersed particles were 115 and 230 micron glass beads. Experimental determination of concentration distribution was made with an impact disk particle counter system. The high inertia of the solid particles resulted in a non-uniform distribution of material in a fully developed turbulent flow. However, the turbulent transfer of particles from the wall toward the center of the pipe was accounted for, and the theoretical distributions compared favorably with experimental results.

125. Spencer, E. A., J. S. Tudhope and Miss J. I. N. Morris, 1960, Flow measurement by the salt-dilution method. Journal of Institution of Water Engineers, 14:215-235.

Sodium dichromate was used as the chemical salt in the salt-dilution method. Tests were performed in 1, 6, and 20 in. pipelines in the laboratory and in a 40 in. pipe at Kinlochleve. The result of the experiments showed that 90 pipe diameters were sufficient for adequate mixing and that an accuracy of ±2 per cent could be obtained with improved instruments.

126. Winternitz, F. A. L., 1960, Comparison of flow-measuring techniques at Kinlochleven hydro-electric station. Water Power, 12 (n. 3): 93-103. Also as Fluids Rept. No. 65, National Engineering Laboratory, East Kilbride.

Field tests are described in which various methods of flow measurement in a 40-inch pipeline were compared. Advanced versions of the current-meter, pitot-tube, salt velocity, and salt-dilution techniques

of gaging the flow were investigated and a comparison made of the systematic and random errors, the convenience of the various methods, and the man-hours required for each technique. This article is a summary of fluids report no. 65 issued by the National Engineering Laboratory, East Kilbride, and relates to a final series of tests carried out at Kinlochleven. Reference is made to fluids report no. 59, which describes the preliminary tests carried out at the same power station. Initially the injection rate was metered by use of a calibrated orifice plate and a 4-ft monometer. Later a gear meter was used to give direct readings of the amount injected over a period of approximately 3-1/2 min., a check on the constancy being obtained by a counter driven from a semi-conductor photocell unit which was triggered 66 times during each revolution of the main drive in the gear meter.

127. Baldwin, L. V. and T. J. Walsh, 1961, Turbulent diffusion in the core of a fully developed pipe flow. American Institute of Chemical Engineers, Journal 7 (n. 1):53-61.

This paper summarizes an experimental study of turbulent diffusion downstream from a line source of heat. The results agreed with predictions based on G. I. Taylor's theory of diffusion by continuous movements; the eddy diffusivity increased from zero at the heat source to a constant asymptotic value for downstream. The Lagrangian correlation coefficients inferred from the diffusion data had shapes similar to those of the Eulerian correlations over most of the range of time and space. Likewise, empirical relations were found for the coordinates of the Lagrangian and Eulerian correlation coefficients over the range of this experiment. In addition, preliminary measurements are reported for a general Eulerian correlation which is a function of both space and time. The results indicate that a special case of this new Eulerian function may be a fair approximation of the Lagrangian correlation.

128. Clayton, C. G., 1961, Measurement of liquid flow. Isotope Research Division, AERE; Radioisotope Review Sheet, C6.

This review is a concise statement of the volumetric measurement techniques of turbulent flow in pipes or open channels. The three techniques, dilution, velocity, and total count, are described briefly, and the author mentions that: "The spread of radioactivity versus time is proportional to the first differential of the concentration of the following product."

129. Corrsin, S., 1961, Reactant concentration spectrum in turbulent mixing with a first-order reaction. Journal of Fluid Mechanics, 11(pt. 3):407-416.

In this article, the power spectra of a passive scalar contaminant undergoing a first-order chemical reaction and subjected to isotropic turbulent mixing are deduced for three different spectral ranges: (1) the inertial convective range; (2) the viscous-convective and viscous-diffusive range for a very large Schmidt number; (3) the inertial diffusive range for a very small Schmidt number. The analysis is restricted to stationary, locally isotropic fields and to systems so dilute that the heat of reaction has no effect on the reaction rate.

130. Feely, H. W., A. Walton, C. Barnett and F. Bazan, 1961, The potential applications of radioisotope technology to water resource investigations and utilization. Final Report Contract AT(30-1) - 2477 U. S. A. E. C., Available from Office of Technical Services, Department of Commerce, Washington, D. C.

These authros attempt to summarize the status of the use of radioisotope in water resource research and utilization. Their paper includes a section which deals with applications of radioisotopes to flow measurement in surface waters, and it includes a section on the isotope velocity method, the isotope dilution method, and the total count method. In addition, several current and pertinent experiments, papers, and field tests are reviewed.

131. Herrmann, W., H. K. Bothe and H. Ohlsen, 1961, (German) Durchflussratenbestimmung nach dem Impulszaehlverfahren (Determination of flow rates by the pulse count method), (A contribution to the investigation of flow of liquids by radioactive indicators). Isotopentechnik, 1 (n. 8), Nov:232-236.

After discussion of three methods of using radioactive tracers for flow measurement (method of concentration, method of travel time between two points, and method of radioactive impulse counts), the impulse count method is treated in detail. For it, the flow discharge $Q = AF/N$, where A is the activity of the injected radioactive material, N = total number of impulses counted, and F = weight or the coefficient of proportionality. No time measurement is necessary. The use of only a small portion, q, of the total flow, Q, for counting impulses is discussed. In addition, the technique of carrying out measurements is described and some experimental measurements are given, along with a schematic representation of the injection apparatus. Finally, extensive discussion is carried out on errors in the method, and experimental results are plotted in two graphs.

132. Hooper, L. J., 1961, Effects of brine dispersion in the Allen salt-velocity method. Journal of Engineering Power, Ser. A. (n. 2): 194-205.

Professor Hooper discusses the effect of dispersion on the Allen salt-velocity method of measuring flow. His theoretical analysis and field tests show that the dispersion of brine in a conduit is proportional to the square root of the distance traveled. The author mentions that: "...the brine slug grows in length as the square root of the distance traveled along the conduit." He also comments that the effect of bends in pipelines is to increase the rate of dispersion and that the effect of a turbulator is to impart a high degree of turbulence to the flow and thus produce better mixing and a more uniform velocity distribution. One of the important requirements for increased precision of the method as suggested by the author, is a check to make certain that the curves of brine passing two electrodes do not overlap. At Alden Hydrulic Laboratory, four 3/4-in. pop-valves were used in a 40-in. pipe to study the effect of the length of the test section on the results.

133. Hours, R., 1961, (French), Emploi des radioéléments en hydrologie, dans la localisation des fuites et la mesure des débits (Use of radioactive elements in hydrology, in the localization of leaks and the measurement of discharges). Bulletin d'Information Scientifique et Technique, (n. 51):63-70.

A general review of the application of radioactive elements in various hydrologic problems, with the stress on localization for water losses and on the measurement of discharges. For the latter, the method of peaks and the method of total count are fully described, as well as six other methods which are briefly outlined (the method of filtering tube, the method of radioactive decay, use of a radioactive tracer created inside a conduit by the neutron flux, a method of measuring radioactive concentration not requiring radioactive tracers, the ionization method, and measurement by ventilation). Also, the radioactive tracers used in these methods are enumerated. Finally, twenty references are listed as the basis for the above review.

134 Lumley, J. L., 1961, Distribution and dispersion in the Euler-Lagrange random walk. Applied Science Research, 10 (n. 2):153-157.

A random walk was developed involving both Lagrangian and Eulerian statistics. Both the spatially and temperally distributed instructions were assumed to be a simple Markov chain. The characteristic function included the Lagrangian correlation, and some possible continuum limit forms for the probability density function were deduced including the telegraph equation, wave equation, diffusion equation, etc.

135. Parker, Frank L., 1961, Eddy diffusion in reservoirs and pipelines. American Society of Civil Engineers, Proceedings (Hydraulic Division), Paper No. 2825, HY3:151-171.

A series of tests were conducted in reservoirs and pipelines to determine the eddy diffusion coefficients. Solutions of dye and a radioisotope were added and then the concentrations were measured in time and space. In this paper, the various methods of analyzing the data which were utilized to determine the eddy diffusion coefficients are discussed. Results of other pipe tests reported in the literature were also analyzed by the various methods. For circular pipes and horseshoe-shaped pipes, full and partially full, the G. I. Taylor formulation and the method of moments gave satisfactory results.

136. Roberts, P. H., 1961, On Bourret's hypothesis concerning turbulent diffusion. Canadian Journal of Physics, 39 (n. 9):1291-1299.

An integradifferential equation proposed on heuristic grounds by Bourret for turbulent diffusion is compared with a similar equation which was derived by Roberts from the application of Kraichnan's approximation to the exact equations of turbulent diffusion and which is itself closely related to an equation postulated by Bourret as a result of further heuristic arguments. A simple generalization of Taylor's model of turbulent diffusion is discussed and is found to obey Roberts equation, but unless the special correlation between the velocity of the diffusing particles is zero it does not obey the equation initially proposed by Bourret.

137. Roberts, P. H., 1961, Analytical theory of turbulent diffusion. Journal of Fluid Mechanics, 11 (pt.2):257-283.

A perturbation method developed by Kraichman to produce homogeneous turbulence was applied by the author to the theory of turbulent diffusion, and closed equations were obtained for the probability distributions of the positions of marked fluid elements released in a turbulent flow. This paper presupposes a thorough understanding on the part of the reader of the statistical theory of homogeneous turbulence.

138. Shumilovski, N. N. and Yu. V. Gushchin, 1961, (Russian), A device for the measurement and automatic control of liquid discharge by means of radioactive radiation. Translated from Atomnaya Energiya, 10 (n. 1):93-94.

A device for the measurement of the rate of flow of highly explosive liquids or liquids at high temperatures or pressures is described. The device was principally a multivane wheel, placed in the fluid stream to serve as the sensing element. A radioactive isotope placed in one or more of the vanes resulted in the sensing of pulsations by the receiver. The accuracy of the instantaneous discharge measurement was ±1.5 per cent for discharges from 0.1 to 1.0 m^3/hr.

139. Skjelbred, Emil, 1961, (Dutch), Stromningsundersokelsokelser i full skala med radioisotoper som sportstoff (Full-scale flow measurements using radioactive tracers). Technisk Ukeblad, 108 (n. 21): 489-493.

According to this author, advanced radioisotopic tracer methods are very valuable in flow measurements. In his view, the superiority of such methods is due to their greater sensitivity, the smaller volumes of tracer necessary, and the wide variety of radioisotopes with different characteristics suitable for them.

140. Teter, G. A., and R. L. Hansen, 1961, Review of publications on the total count method for measurement of flow. U. S. Bureau of Reclamation, Intradepartmental Report, June 5, 1961.

The general theory of the total count method together with convergent flow and divergent flow is presented. The author recognizes that the advantages of the total count method as compared to those of the salt-velocity and two-point radiotacer methods are that it is not limited to closed conduits and that it can be used in conduits of any shape, kind or size.

141. Anders, O. U., 1962, Activation analysis for plant-stream monitoring. Nucleonics, U. S. A., 20 (n. 2):78-83.

A prototype analyzer was constructed and three experiments were performed to establish its practicability. The experiments proved the feasibility of constructing such an analyzer based on the principle of activating the desired stream constituents. First, two coils were made out of polyethylene tubing (1/2-in. diameter). Then, a Ra-Be source emitting 1.3×10^5 fast neutrons per second was put at the center of one

of the coils, while the second coil was put around a Na I (T1) scintillation counter. Next, the two coils were connected by 1/4-in. diameter polyethylene tubing. The first coil acted as an irradiation vessel, while the second coil acted as a detector. Finally, the ouput of the detector was transmitted to a voltage supply and amplifier and then to a rate-meter and a penrecorder which would record the analogue signals produced as a result of gamma rays. In such a setup, it is necessary to use short-lived activation products. The author mentions that a drawback to the stream analyzer is the interference of other elements which give rise to short-lived activation products.

142. Anonymous, 1962, Flow measurement by means of tracrs. Department of Scientific and Industrial Research (Notes on Water Pollution) (n. 19), December.

The salt-velocity, salt-dilution, and integration methods of flow measurement are discussed in this paper. Criteria for the choice of tracers are given and the properties of common salt, lithium compounds, Br^{82}, sodium nitrate, manganous sulphate, sodium dichromate, rodamine B, and several others as tracers are mentioned. Geiger tubes were reportedly used for the measurement of β-particles (fast electrons), and scintillation counters for γ-particles (electro-magnetic radiation). The possibility of the use of radioactive tracers in the rate of flow measurement of gases and solids such as activated sludge, river silt, or even pebbles, is also discussed.

143. Baehr, Franz Walter, 1962, (German), Wassergeschwindigkeitsmessungen mit Hilfe radioaktiver Isotope (Water velocity measurements by means of radioactive isotopes), Part I: Die Wasserwistschaft, 7, July:173-177.

This first of two parts deals with stream measurements. Radioactive material, injected into a river, is measured as a function of time at several places along the river. From these response graphs, the travel time of water between the points is measured, and from these measurements the average water velocity along the river is determined.

144. Baeno, Baehr and Franz Walter, 1962, (German), Wassergeschwindigkeits messungen mit Hilfe radioacktiver Isotope (Water velocity measurements by the means of radioactive isotopes). Part II: Die Wasserwirtschaft (Germany), August 1962:222-226.

This article, which is a continuation of an earlier one, deals with the measurement of ground water velocities. It describes in detail the measurements of effective water velocities under the ground between wells.

145. Bailey, H. R. and W. B. Gogarty, 1962, Numerical and experimental results on the dispersion of a solute in a fluid in laminar flow through a tube. Proceedings Royal Society of London (ser. A), 269:352-367.

The longitudinal dispersion of a solute was studied for the process by which pure solvent slowly displaces a solution in a circular tube. Good agreement was obtained between a numerical solution of the partial differential equation describing the process and experimental results for displacement of a dilute solution of potassium permanganate by water. The range of applicability of Sir Geoffry Taylor's approximate solution is discussed. An improved approximate solution is presented with a much wider range of validity. This improved approximation is based on the numerical solution of the equation describing the process. For the case of laminar flow, the concentration of solute, as a function of distance along the tube, x, radial distance from the axis of the tube, r, and time, t, is described by the partial differential equation:

$$D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial r^2} + \frac{1}{r}\frac{\partial c}{\partial r}\right) = \frac{\partial c}{\partial t} + U_o\left(1 - \frac{r^2}{a^2}\right)\frac{\partial c}{\partial x} . \qquad (1)$$

When longitudinal diffusion is neglected, the equation becomes:

$$D\left(\frac{\partial^2 c}{\partial r^2} + \frac{1}{r}\frac{\partial c}{\partial r}\right) = \frac{\partial c}{\partial t} + U_o\left(1 - \frac{r^2}{a^2}\right)\frac{\partial c}{\partial x} . \qquad (2)$$

Equation 2 is solved subject to the initial condition that $c = 1$ at $t = 0$ for all x. Concentration as a function of distance along the capillary tube was determined through the use of a model 14 Cary spectrophotometer.

146. Baldwin, L. V. and W. R. Mickelsen, 1962. Turbulent diffusion and anemometer measurements. American Society of Civil Engineers, Proceedings 88 (EM 2):37-69.

Theoretical prediction of diffusion in homogeneous turbulent fields on the basis of the Taylor theory of diffusion by continuous movements requires knowledge of the Lagrangian turbulent velocity correlation coefficient. Although a direct theoretical connection between the Lagrangian and Eulerian correlation coefficients has not yet been

established, it has been shown that an empirical relation can be established. Eulerian correlation coefficients from hot-wire anemometer measurements were compared with Lagrangian correlation coefficients derived from diffusion measurements in a homogeneous turbulent flow. From this comparison, a relation was found that permits a direct prediction of turbulent diffusion from hot-wire (Eulerian) measurements of the turbulent field. In addition, some measurements of a mixed space-time Eulerian correlation coefficient are described, and a possible direction for further research is presented.

147. Carlson, Roy, Bernt Cederberg and Knut Ljunggren, 1962, Measurement of the water circulation in a high-pressure natural-circulation boiler. Combustion, June 1962: 25-30.

Two methods of measuring water velocity in boiler tubes are suggested in this paper, namely: the radioactive vane method and the injection method. Both methods make use of radioactive materials. The radioactive vane method as suggested by Professor O. Hammar makes use of a propeller equipped with two radioactive sources fitted on its blades. In one source, 10 mC of Co^{60} was placed and in the other source, 3 mC. The two sources were 120 degrees apart. The propeller, driven by the flow of water, put the two sources alternatively in the field of a detector, which in turn gave rise to signals. Thus, the water velocity could be determined. The injection method was also suggested by Professor O. Hammar. A small quantity of radioactive material was injected into a line and two detectors at a known distance apart picked up signals from the passage of the radioactive material. After determination of the exact time of passage, the velocity of water could be calculated. To conclude, the result of experiments are reported and graphically depicted. The conclusion drawn from the tests was that it is possible to measure water velocity with a high accuracy without disturbing the normal functioning of or introducing any major alterations into the boiler body.

148. Clayton, C. G., 1962, Accurate measurement of turbulent flow in pipes using radioactive isotopes. United Kingdom Atomic Energy Authority, Isotope Research Division, DPR/INF/268 (see also "Atom", December 1960).

This paper covers techniques, instrumentation, equipment and methodology for applying radioisotopes to flow measurement, viz., the salt-velocity, salt-dilution, and total count methods. The accuracies claimed are of the order of one per cent for the salt-velocity and salt-dilution methods. The figures obtained were arrived at by laboratory measurement in a weight calibrated system. Also included is a discription of a very precise constant-rate injection device.

149. Clayton, C. G. and D. B. Smith, 1962, The measurement of water flow in turbulent motion using radioactive isotopes. Water Research Association, Special Report No. 2, Summary Paper for Item 10.

Isotope dilution, isotope velocity, the total count, and the coninuous sample method are discussed in this paper. These radioactive tracer methods, as the authors mention, are similar to chemical methods with the exception that the introduction of radioactive materials presents certain practical implications.

150. Hooper, L. J., 1962, Discharge measurements by sharp-edged orifices and salt-velocity methods. ASME paper 62-HYD-9 for meeting May 21-23, 1962.

An experiment was performed to determine the discharge in a 48-in. diameter pipeline by means of the slat-velocity method. The results were used to determine the constant of an orifice installed in the same pipeline. In the salt-velocity method, the time of travel was measured as the time interval between the centers of gravity of the two electrode curves.

151. Hull, D. E., 1962, Dispersion and persistence of tracer in river flow measurements. International Journal of Applied Radiation and Isotopes, 13:63-73.

In this article, the total count method is demonstrated to be useful for accurate measurement of the flow in turbulent natural streams over a range of 5-1000 ft^3/sec. Duplicate measurements using A_u^{198} were reproducible to 1 per cent, and the absolute accuracy was within 5 percent. According to the author, the distance along the stream, from where the tracer is added to where it is counted, must be great enough to allow complete transverse mixing of the tracer. The longitudinal dispersion of the tracer wave can be represented roughly by a Gaussian error function over a small segment of a stream. The mixing coefficient D varies with the dimensions and contour of the stream bed. Values from 80-270 ft^2/sec were found for adjacent segments of the same stream. A formula was derived for the distance required for complete transverse mixing in a turbulent stream: $L_{min} = aQ^{1/3}$. The value of a is about 200 when the tracer is added at one edge and about 50 when it is added in mid-stream. This paper describes tests made on the south fork of the American River in 1958, the object of which was to determine the range of distance over which satisfactory measurements can be made. The lower limit was set by the criterion of complete mixing. The upper limit was set by loss of tracer through precipitation or adsorption on the soil or on algae in the streambed.

152. Hull, D. E. and M. Macomber, 1962, Flow measurements by the total-count method. Proceedings of the 2nd U. N. International Conference on the Peaceful Uses of Atomic Energy, 19:324-332.

This paper studies the application of the total-count method to open streams and describes the experiments performed. The advantages stated for the total-count method are: it is applicable to any kind, size, or shape of conduit, open or closed; it does not result in a pressure drop or a loss of hydraulic head. Besides, as the author mentions, the principle of divergent stream makes it possible to conduct the experiment only on a portion of the flow. This principle enabled the experimenters to apply the total-count method to an open stream with the only requirement that the radiation detector be exposed to the flow in a geometrical configuration that could be duplicated in the laboratory. A test on the Navarro River in Mendocino County, California, was conducted for the purpose of studying the stability of gold isotopes in water solution and also mixing properties. Another test was run on the American River above Sacramento, where confluence of two branch streams provided more mixing. The author concludes his paper by stating that the total-count method can be used to check other types of flow meters.

153. Hutton, S. P. and G. B. Murdoch, 1962, Comparative flow-measurement tests at Finlarig Power Station (Part One). Water Power, 14 (n. 10):391-395, 404.

A series of comparative flow-measurement tests were carried out at Finlarig in North Scotland. It was decided to measure the discharge by seven different methods: dilution, salt velocity, pressure (Gibson), upper current-meter, pitometer, lower current-meter, and the standing-wave flume. A thermodynamic method was also applied which determined the turbine efficiency and from which the discharge could be calculated.

154. Hutton, S. P. and G. B. Murdoch, 1962, Comparative flow-measurement tests at Finlarig Power Station (Part Two). Water Power, 14 (n. 11): 438-444.

This part of the report is a description of the tests themselves. The results were compared by plotting them in a non-dimensional form. The turbine-nozzle discharge coefficient $C_D = Q/Qth$ (Q is the measured flow and Qth is the theoretical flow) was plotted against the percentage spear opening. The plotted values form a band with an overall variation of 5 per cent. Current-meter method gave the largest flow rates and Gibson method the smallest. The results obtained from the current-meter and dilution were similar and those from pitometer, tail-race

flume, and salt-velocity measurements results were in between the other two methods. The author further states that a large number of similar tests elsewhere will be necessary before any conclusion can be drawn regarding the relative accuracy and mertis of these methods.

155. Johnston, W. H., A. F. Findeis, and M. Vestal, 1962, High dilution on-stream isotopic tracer techniques, proceeding series. Radioisotopes in the Physical Sciences and Industry I .

"The present paper concerns large-scale applications in which isotope tagging is done on a component of main flowing fluid or stream without subsequent mainline separation. Equations are derived which relate the required levels of tracer concentrations, the instrumental background, the efficiency of the detector, the required statistical reliability, the time desired for the measurements of sample and background, the stream flow rates, and the tracer nuclide. These equations are shown graphically and allow a ready selection of the tracer concentrations for specific applications. The sampling program for large-scale tracer applications is analyzed for steady state and pulse injections. In the latter case, the longitudinal mixing is treated by the concept of eddy diffusion coefficients. By estimating certain parameters, the longitudinal tracer detection range and the first arrival time are obtained as a function of distance between injection and collection. For high-dilution on stream radiotracing with beta-emitters, the detectors are large low-level internal-gas-tube counters, foil-flow counters, and plastic scintillators. New anticoincidence counters are presented. The advantages of low-atomic-number shielding are emphasized. Present developments in stable transistorized electronics for low-level counting are shown. A new amplifier and a new tunnel-diode adder circuit are described. Examples are given of several new applications of high-dilution on-stream tracers to problems of source-identification of pollution of rivers and streams."

156. Kato, M., K. Kawazoe and O. Sato, 1962, (Japanese), Hōshasei tsuidekiho ni yoru kasen ryūsui ryūka sokudō no sokutei ni kansuru kenkyū (Studies on the measurement of the flow rate of a river stream using radioactive tracers). Radioisotopes (Tokyo), 11 (n. 1):23-32.

Flow rates were measured using radioactive tracers over an 80 km. reach of the Sorachi River. Approximately 30-100 mc. of I^{131} and Na^{24} were injected in the upstream reach. The samples were analyzed by precipitation of AgI^{131} of formation of $Na^{24}Cl$ by an ion exchange process. Detection of the activity of the collected samples

was by 6M tube and scintillation detector. A detector was attached to a float in the river and calibrated by means of the discrete samples. A peak to peak measurement then gave the flow time. Accuracies of ±1 percent and ±2 percent were obtained for the 10 km. and 30 km. reaches respectively.

157. Leon, P. R. L., 1962, The use of radio isotopes for river flow gauging. N. Z. Engineering, October 15, 1962:373-375.

This is a report of the use of radioisotopes in a demonstration application to Hacking River and it includes further information concerning costs and other relevant details of the method. The equation used for the determination of the flow rate was $Q = AF/N$, where Q = discharge in cusec, F = meter facotr, A = activity in mullicuries and N = total count. The meter factor "F" was found in the laboratory under static conditions.

158. Meyerink, E. S. C. and S. K. Friedlander, 1962, Diffusion and diffusion controlled reactions in fully developed turbulent pipe flow. Chemical Engineering Science, 17, Feb. 1962:121-135.

Experimental data are reported for the mass transfer rate of substances which dissolve from the wall of a pipe into water or aqueous solutions of sodium hydroxide in fully developed turbulent pipe flow. The dissolving substances were pressed cylinders of benyoic acid, cinnamic acid, or aspirin. Experimental results are presented for benyoic and cinnamic acids with and without chemical reaction for developing and fully-developed concentration distributions. Data for aspirin for the fully developed distribution chemical reaction are also reported. Finally, a simple theoretical expression is derived for the reacting system which correlates the data well over much of the range of ratios of base concentration to acid concentration.

159 Spencer, E. A., 1962, The dilution method of flow measurement. Water Research Association, Special Report No. 2, Summary Paper from Item No. 9.

The two distinct techniques of the dilution method are briefly discussed. According to the author, the first technique is the injection of a concentrated chemical at a constant rate and the second is the sudden injection method.

160 Anonymous, 1963, Measuring ground and surface water. Construction Engineering:506-507.

This is a summary of a symposium on "Measurement in Hydrology" held at Reading University in Britain. Discussions on rainfall measurement, surface water measurement and ground water measurement were on the program of the symposium. Among the points brought out were the following: transpirational losses are very important in rainfall measurement in open country, and thus a simple weighable lysimeter was developed which could measure such losses. Mr. Collinge has designed a rain gage which could operate for a month without attention. Systematic and random errors in rainfall gaging were discussed and suggestions were made concerning the sampling density requirements for rainfall measurements. Also, discharge measurements were discussed and Mr. P. O. Wolf suggested that the most important quanlities of a measurement device were: accuracy, ease and speed of operation, stability, reliability, and portability. Principles of dilution method and radiotracers in open channel flow measurements were elaborated on and Dr. E. C. Childs discussed the use of hydraulic models in the study of drainage problems.

161. Anonymous, 1963, Radioisotopes in hydrology: An IAEA symposium. Nucleonics, 21:94.

A short summary of discussions in the symposium is presented in this paper. The use of such tracers as Cl^{36}, tritiated water (HTO), and Cr^{51}-EDTA (ethylene diamine tetra-acetic acid) in ground water studies and Strontium-89 and -90 for investigation of water balance between precipitation and run-off to rivers were discussed. Japanese investigators reported on the use of radioisotopes in flow measurements, measurement of river bed variations during floods, and groundwater movement studies. Other speakers reported on the use of radioisotopes in France, the United Kingdom, and Australia.

162. Barsby, A. and J. A. Cole, 1963, The calibration of two flumes by salt dilution. Water and Waste Engineering, 67 (n. 808): 219-222.

Full-scale calibrations for low flow rates were required for two flumes having trapezoidal throats. The 'gulp" method of injection was used, in which a known quanitity of injected chemical forms a fairly brief pulse. NaCl, KCl, and KH_2PO_4 were used at concentrations in the range of 2 to 7 per cent. Downstream concentrations were determined by colorimetric and photometric laboratory analyses. In addition, some field analyses were made of chloride content, using Mohr's method.

163. Clayton, C. G. and D. B. Smith, 1963, A comparison of radioisotope methods for river flow measurement. Wantage Research Laboratory, Atomic Energy Research Establishment.

"The Dilution, Continuous Sample, and Total Count Methods have been used in a comparative study of radiotracer methods of river flow measurement in the Aylburton Brook in Gloucestershire and the Usway Burn and Alwin Rivers in Northumberland. These are three rivers of differing geological character with flow rates varying between 2.5 ℓ/s and 3 m^3/s. In all tracer methods of flow measurement the distance between the measuring point and the point at which the tracer is introduced should be great enough for complete lateral mixing to have occurred. On the other hand, it should not be so great that longitudinal dispersion is excessive or that tracer is lost by adsorption on the river bed. Dispersion depends on the hydraulic characteristics of the stream and is intrinsic to the method. Adsorption depends on the choice of tracer and on the geological nature of the river bed. From this latter point of view H^3 is ideal as it is not adosrbed; but it is difficult to measure, and its progress in the river cannot be followed directly. Other tracers are more convenient but they may be adsorbed. The degree of adsorption of Na^{24}, Br^{82} and P^{32} in the form of $NaHCO_2$, NH_4PO_4 and NaH_2PO_4 has been studied by comparison of measurements at several points downstream of a common injection point and by introduction of titrated water (HTO) simultaneously with each of the three tracers. It has been shown that P^{32}, which was expected to undergo a high degree of chemisorption, is valueless as a tracer for river flow measurements when used without carrier although there is a significant decrease in error when it is used with carrier. Na^{24} and Br^{82} show no evidence of adsorption at distances much greater than that required to give lateral mixing although at a distance of over 600 m. in the slowest-moving river there is some evidence of Na^{24} removal. Some observations of the degree of lateral and longitudinal dispersion which affect the general application of tracer techniques to river flow measurement will be presented. It is concluded that all three methods can be satisfactorily used. The Continuous Sample Method is ultimately preferred as it gives the highest accuracy for the smallest quantity of tracer."

164. Clayton, C. G., J. W. Webb, and J. B. Whittaker, 1963, Dispersion of gas during turbulent flow in pipes, British Journal of Applied Physics, 14 (n. 11):790-794.

An expression for the dispersion of a compressible fluid in turbulent motion in a pipe is derived. The solution is based on Taylor's theory for dispersion during incompressible fluid flow but allows for the continuous increase in linear velocity which can occur during turbulent

flow of a compressible fluid. The thoery was checked experimentally by injecting radio active Kr^{85} into air flowing turbulently in a smooth pipe. The width 2S of the tracer at a distance L along a pipe of diameter 2a and Fanning friction factor γ was shown to be given by the equation: $S^2 = 3.24 \times 10^8 \gamma^{0.96} (L/a)^{0.135} La(U_L/U_o)$, where U_L/U_o is the ratio of the mean velocities of flow at the point of measurement and the point of injection. This equation is compared with that predicted theoretically, which is of the form $S^2 = F\gamma^{0.5} La(U_L/U_o)$, where F is a constant.

165. Gardner, R. P. and J. W. Dunn, 1963, Stream flow measurement by an inert tracer pulse technique. Nuclear Science Engineering, 15 (n. 3):338-341.

Volumetric flow rates were determined by the use of an inert tracer and activitation analysis. The inert tracer was introduced into a stream, and samples were taken further downstream and irradiated in a nuclear reactor. Gamma spectroscopy was used to count the gamma rays of the radioisotope of the inert tracer. The tracer, among other things, should be highly sensitive to activation. The author proposes an increase in the amount of injected tracer and larger samples to increase the sensitivity.

166. Godfrey, Richard G. and Bernard J. Frederick, 1963, Dispersion in natural streams. U.S.G.S., Prepared in cooperation with the U.S. Atomic Energy Commission.

"Eleven tests were conducted to study the dispersion patterns of a radiotracer in five natural stream channels and in one canal. The radiotracer was injected as a fine source. The patterns of dispersion that were observed in these channels were compared with patterns predicted by the theoretical models for one-dimensional flow developed by Taylor and other investigators. Analysis of several sections in each of the six reaches shows that the available theoretical models are not adequate to describe patterns actually observed. Dispersion coefficients determined from the test data are from 2 to 30 times greater than those predicted by theoretical models. It is apparent that a better understanding of the dispersal phenomenon is needed in order to predict patterns in natural streams."

167. Guiserix, J., G. Grandclement, R. Hours, H. André, R. Wolf and R. Peres, 1963, Flow measurements carried out in France by means of radioactive tracers by the integration method. United States Atomic Energy Commission Division of Technical Information (AEC-tr-6303).

"The authors describe their experiments with the total count method in measuring the discharges of rivers and of hydroelectric plant penstocks. Their procedure was to sample a portion of the current during the passage of the activity wave by means of gauges and constant-level tanks. The sample and an aliquot part of the injected activity was counted in the same geometry. The method has several advantages over the conventional method using a submerged probe. First it avoids the difficulties presented by the counting geometry, both in rivers and in penstocks: it likewise makes it possible to determine the statistical counting accuracy and, by making several samplings in the measurement section, to verify whether good mixing conditions are present. Further, since it allows the use of a scintillation counter and concentration of the tracer by chemical means, the method, by comparison with the conventional technique, requires a minimal activity to yield a given degree of accuracy. In conclusion, the authors give the results of measurements of rivers and penstocks and state their views on the future of the total count method."

168. Hours, R., J. Guiserix, G. Grandclement, H. André, R. Wolf and R. Peres, 1963, (French), Les mesures de débits effectives en France à l'aide de traceurs radioactifs par la méthode d'integration (Discharge measurements carried out in France by the integration method with radioactive tracers). La Houille Blanche, July 1963, (n.4) :459-473.

"French research on this subject during the past two years has been concerned with the determination of conditions under which the method can be applied and the type equipment required. After reviewing the principle of the method, the basic conditions governing its use and the various tracers employed: the authors give a detailed description of the actual measurement procedure and the equipment. The article concludes with an exposé of the principal test to hich it has been subjected."

169. Hull, E. C., 1963, Total-count demonstration for USBR personnel at Richmond Socal Refinery. California Research Corporation, Richmond, California, File 280.240.

The paper is a description of a total-count flow measurement demonstration carried out on September 6, 1962, in the Richmond

refinery of the Standard Oil Company of California. A discussion of the possible sources of error and experimental data is also presented.

170. Kato, Masao, O. Sato, Y. Morita, M. Kohama and N. Hayashi, 1963, (Japanese), A study in river engineering on the results of field measurements about flow velocities using radioisotopes in the Sorachi River, Japan. Paper SM-38/29 for IAEA Symposium on Application of Radioisotopes in Hydrology, March, 1963.

Na^{24}, Br^{82}, I^{131}, and salt water were used as isotope tracers in the Sorachi River below Kanayama Dam for flow measurements. Both direct and indirect measurements were used and Scintillation counters were found more sensitive than Geiger counters for underwater detection.

171. Kobayashi, M. and A. Nukazawa, 1963, (Japanese), Measurement of river dilution and flow by means of radioactive tracers and activation analysis. Radioisotopes in hydrology, Proceedings of the symposium on the application of radioisotopes in hydrology held by the International Atomic Energy Agency, Tokyo:433-449.

A comparison was made of the effectiveness of Br^{80} and Br^{82} by the continuous injection of NaBr and NH_4Br as non-active tracers. Radioactive NaCℓ served to indicate the arrival of the non-active tracers. A small portion of the water samples was irradiated in a neutron flux of about 4×10^{11} n cn^{-2} s^{-1}. From the activities of Na^{24}, Br^{80}, and Br^{82}, the dilution rates were determined. Long irradiation periods with subsequent cooling periods for decay of the short-lived isotopes gave the best results.

172. Lee, Jon and Robert S. Brodkey, 1963, Light probe for the measurement of turbulent concentration fluctuations. The Review of Scientific Instruments, 34 (n. 10):1086-1090.

In this paper, the development of a light probe is discussed. The instrument built was one based on the principle of transmission of a light beam through a small sample volume by means of thin fiber glass lines. A light-absorbing dye solution in water formed the flow system and a photomultiplier was used to produce a current linearly proportional to the light intensity, which in turn was measured by the voltage drop across a resistor. Experiments were conducted and the average and the root-mean-square of local concentration fluctuations were measured. A limitation of the system was that mixing intensities could only be measured until the system was 90 per cent mixed.

173. Litwiniszyn, J., 1963, On a certain problem of diffusion with simultaneous linear accumulation. Bulletin de l'Academie Polonaise des Sciences, Series des Sciences Techniques, 11 (n. 5):149-153.

The author solves the differential equation,

$$\frac{\partial u}{\partial \tau} + V \frac{\partial u}{\partial x} = A \frac{\partial^2 u}{\partial x^2} - Bu + C \int_0^{\tau} u(x, \tau)\, d\tau ,$$

where $u = f(x, \tau)$ denotes the concentration of the diffusing medium, and where the medium is in the process of diffusing in one direction with an absorption term Bu and an accumulation term

$$C \int_0^{\tau} u\, d\tau .$$

174. Sayre, W. W., H. P. Guy and A. R. Chamberlain, 1963, Uptake and transport of radionuclides by stream sediments. United States Geological Survey Professional Paper 433-A:35.

This paper is not directly applicable to the subject of this bibliography because it deals with the indirect dispersion of radionuclides absorbed on sediment particles. It does, however, give background information on turbulent diffusion and the dispersion of radioactive wastes in streams and estuaries.

175. Shen, J., 1963, An analog solution of the turbulent-diffusion equation for open-channel flow. United States Geological Survey Professional Paper 450-E, article 233:169-171.

The electrical analog of the diffusion equation is expounded and schematics are developed which would act in accordance with the electrically analagous equation. The boundary conditions of an open channel are discussed and a means suggested for imposing them on the analog. No quantitative values are suggested for the analog board.

176. Svantesson, Nils L. and M. Sundberg-Falkenmark, 1963, Flow analysis with radio-isotopes (applied to a hydro-electric plant). La Houille Blanche, (n. 3), May-June 1963:225-268.

The dilution method of flow measurement is discussed and is referred to as the total-count method. An equation for disharge determination is presented which is : $Q = M / \int_0^{\tau} c\, dt$, where Q = discharge, M = mass of the injected tracer, C = instantaneous concentration (at time t) and T = time of radioactive wave passage. The method was used in a

power plant with Kaplan turbines and a head of water of about 12 m. Na_2CO_3 was used as the radioactive tracer and was injected near the intake. At 75 m downstream, measurements of concentration were carried out in 10 different verticals with two measuring points in each. Parameters were also developed to define turbulence in the water ways of the plant. Use was made of the statistical theory of turbulence which assumes that the instantaneous velocities have two components: the mean and the turbulent fluctuation.

177. Timblin Jr., L. O. and A. J. Peterka, 1963, Use of radioisotopes for open-channel flow measurements. U. S. Bureau of Reclamation, Paper No. SM-38/15:37-61.

"With techniques based upon the salt-dilution method, radioisotopes can be used for discharge measurements in open channels such as canals, streams and rivers. Field measurements with radioisotopes in canals discharging up to 8000 ft^3/s have been made by the Bureau of Reclamation. The conditions of the field measurements are described in this paper, and important observations are made relating the results to the use of these methods for discharge measurements in rivers. The field tests were performed to study the general feasibility of the use of isotopes for discharge measurements in open channels and to investigate some of the important field problems which are still under study. These include the field requirements for necessary transverse mixing of isotopes with the flowing water; sorption of the isotopes by suspended sediments, channel flow surfaces and aquatic plants; and improvement of field procedures and equipment. Results of present laboratory and field tests led to a proposed method for employing radio isotopes in river-discharge measurement to provide continuous or periodic discharge determinations."

178. Buchanan, Thomas J., 1964, Time of travel of soluble contaminants in streams. Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, 90, paper 3932 (n. SA 3):11-12.

In April 1963, experiments were conducted to determine the time-of-travel of a Rhodamine B dye in a stream. The apparatus employed for the determination of dye concentrations was a fluorometer, an instrument which has a large range of sensitivity and is at the same time very rugged. It was found that the wave of concentration spreads out as it moves downstream. Included in this report is a plot of the elapsed time versus relative concentration on Swatara Creek which exemplifies the process of spreading out. "The technique developed by the U. S. G. S. for time of travel measurements appears to have many

other applications, particularly for the study of dispersion. It should be possible to study the movement of dye in a stream in relation to the geometry of the channel and stream system to obtain a better understanding of dispersion, velocity of floor waves, long-term movements of contaminants in solution, and the relation of velocity-depth-width-discharge to the use of energy in a stream system."

179. Clayton, C. G., 1964, The use of a pump to reduce mixing length in the dilution method of flow measurement. United Kingdom Atomic Energy Authority Research Group Report.

According to this report, in the dilution method of flow measurement, samples should be removed at a point downstream beyond that at which the tracer is uniformly mixed over the cross section of the fluid. This condition often imposes a practical restriction to the application of the method when suitably long lengths of conduit are not available. If a pump can be included in the measuring section, it may be used to reduce the mixing distance. An experiment was carried out to determine the mixing efficiency of a mixed-flow pump. Results obtained show that, with either a four position or single orifice injection system, the mixing by the pump is almost complete. Therefore, from the point of view of operating the dilution method in this manner, an additional straight section of pipe does not appear to be necessary. The advantages to be gained from restricting the test section to the main circulation pump, especially in C. W. systems in power station, underline the value of extending these experiments to larger pumps of all types.

180. Evans, R. A. and R. L. Ely, 1964, Derivations of tracer balance equation for flow measurements. International Journal of Applied Radiation and Isotopes, 15 (n. 5):309.

A mathematical derivation of the equation $Q = A / \int_t c\,dt$ is given, which more rigorously defines the conditions under which the equation is valid than was possible in the past. The equation is based upon the assumption that there are no sources or sinks of the tracer once it is introduced into the stream. Further restrictions imposed upon the use of this equation are: (1) $\partial Q/\partial t = 0$ during the period of measurement, (2) $\int_t c\,dt$ must be independent of location on an arbitrary surface, which includes the measuring point.

181. Fodor, J., 1964, New method for measuring gas flow speed by means of radio-isotopes. Acta Techn. Hung., 64 (n. 1-2):162-169.

A method is presented for measuring relatively great speeds of gas flow by means of radioactive isotopes. By this method, the speed of flow can be measured without sampling. To this end, the isotopte $CH_3{}^{131}I$ was employed. By the use of this isotope, which has a specific radioactivity of 1~5 mc/ml, gas flow speeds within the range 3.5 to 9.3 m/sec could be measured. It was discovered that the automatic type of measuring equipment is suitable for the measurement of great speed for a not too long conduit.

182. Frederick, Bernard J., 1964, Measurement of turbine discharge with radioisotopes. U. S. Geological Survey Report TEI-855.

Five experiments were conducted in the laboratory in a 2-inch diameter pipe. Gold-198 was injected into the pipe at a constant rate, and the discharge was then computed from

$$Q = q\,\frac{C_1 - C_2}{C_2 - C_o} \quad \text{and} \quad Q = \frac{C_1 V}{\int_o^{\infty} (C_2 - C_o)\,dt} \; .$$

These values of discharge were then compared with the results of volumetric measurements. In addition, eleven field tests were conducted at Dale Hollow Dam near Celina, Tennessee, using constant rate injection of gold-198 into the penstock intakes of units 1 and 2. Samples for determination of C_2 were obtained from the draft tube of the turbine. The computed flow rates were compared to values obtained from flow integrators connected to the turbines. The integrator ratings were based on Gibson Test data.

183. Gardinrr, J. A., 1964, An accurate flowmeter for a tracer liquid Instrument Practice, July 1964:721-726.

In this paper, the development of an instrument for the delivery of a stream of tracer liquid at a constant and known rate is described. The flow of the new apparatus rates could be determined within an accuracy of ±0.05%. In the main, it consisted of a rotameter with a float. The deviations of the float from a fixed position were electro-optically sensed, and impulses thus created actuated an electronic circuit which regulated a valve in the system for the purpose of flow rate adjustment. The apparatus also included a flow rate measurement section. This section had a pneumatic means of diverting the liquid stream into a receptacle and a timing mechanism which was based on the refraction of a light beam and the illumination of a photo-conductive cell. Results of the tests conducted are reported in two tables.

184. Gardner, R. P. and J. W. Dunn III, 1964, A radioactivity indication method for determination of flow velocities (only one measurement is necessary). International Journal of Applied Radiation and Isotopes, 15 (n. 6):339-344.

The authors describe radioactivity detection method, for the determination of flow velocities, which is more precise and simpler than previous methods. It consists of exchange counting inside of the stream followed by counting and calibration of only one instantaneous probe, taken from the stream during the passage of injected indicators. This method can be applied either by using the principles of indicator balance (total counting) or indicator rate balance (dilution) for the measurements of stream velocity. A series of six stream measurements are made by using unique probes and the principles of indicator balance. The velocities in these measurements were 45 to 75 ft/sec. The results obtained coincided within ±4% with the U. S. Geological Survey calibration, and the average deviation of all experiments was ±1. 1% . (Translated from authors' abstract)

185. Glover, R. E., 1964, Dispersion of dissolved or suspended materials in flowing streams. United States Geological Survey Professional Paper 433 B:32.

The one dimensional differential equation for diffusion,

$$\frac{\partial S}{\partial t} = K_x \frac{\partial^2 S}{\partial x^2} - V \frac{\partial S}{\partial x} \quad ,$$

is solved and then extended to two and three dimensions by use of a product law for constructing solutions to partial differential equations. Values of longitudinal and lateral diffusion coefficients are presented for several sets of data and compared with analytically predicted values based on the works of Taylor and of Elder.

186. Haffner, J. W., 1964, Radioisotopes for on-stream analysis. ISA Journal, 11:78-82 (Part I, April), 75-78 (Part II, May)

In the first part of this paper, radioactive materials are recommended for a more accurate on-stream analysis. A brief summary of the most suitable radioactive materials is included, and their use in tracer-type techniques and attenuation-based techniques is discussed. Part two of the paper describes the basic parts of a mass flow gage, which consists mainly of an S-shaped pipe, a density loop, and a torque loop. The gage measures the product of the density and velocity of fluid which is the desired mass flow. Part two also includes a description of a

double-thickness/double-density gage which is a modification of the standard radioactive attenuation gage. In addition, the principle of a Bergllium Monitor and neutron techniques are described.

187. Koutsky, J. A. and R. J. Adler, 1964, Minimization of axial dispersion by use of secondary flow in Helical tubes. Canadian Journal of Chemical Engineering, 41-42:239.

It has been known for some time that many continuous chemical reactors give the greatest conversion when axial dispersion is minimized, i.e., when plug flow occurs. This paper considers the problem of attaining plug flow in continuous flow systems. In the view of the authors, a tube wound into a helix provides a convenient and efficient means of producing secondary currents which promote plug flow. On the basis of tracer distribution tests and pressure drop data, it is conclusively shown that helical coils are far superior to straight tubes or packed beds in minimizing axial dispersion and producing plug flow. Finally, a discussion of the mechanics which either promote or inhibit axial dispersion leads logically to the concept of using secondary flow to inhibit axial dispersion.

188. Lee, J. and R. S. Brodkey, 1964, Turbulent motion and mixing in a pipe. American Institute of Chemical Engineering, Journal, 10 (n.2):187-193.

Turbulent mixing of a dye solution injected at the center of a pipe was studied by the authors by means of a new light probe developed for the measurement of concentration fluctuations. The measurements of mean concentration and intensity of concentration fluctuations were made both along the axial distance and across the pipe. The concentration fluctuations persisted longer at the center-line region than anywhere else; this persistence suggested the use of the decay of intensity at the center as an upper limit. Elsewhere, approximately 99 per cent of the initial intensity decayed within 7.5 ft (30 L/D). The concentration spectra along the axial distance indicated that the eddies initially undergo a scalar energy cascade. Because of the huge difference in the kinematic viscosity and molecular diffusivities, the concentration spectra extend much farther toward high curve numbers than the velocity spectrum. Apparently a state of imbalance results between the supply of small eddies and their dissipation which is marked by the appearance of a small hump in the spectra. The phenomenological approximations of Corrsin and of Beek and Miller could be used for the practical problem of predicting the decay of the intensity of the concentration fluctuations or mixing in the pipe geometry studied.

189. Ostrem, Gunnar, 1964, A method of measuring water discharge in turbulent streams. Geographical Bulletin, No. 21, May, 1964 (Publication of the Geographical Branch, Ottawa, Canada).

"The salt method was employed during the summer field season of 1963 in studies of the Lewis River, carried out at the northeast corner of the Barnes Ice Cap, north-central Baffin Island, N. W. T., as part of the North-Central Baffin Island Survey of the Geographical Branch. As far as is known, it was the first time this technique was used in Canada. Its introduction had a twofold purpose: (a) to measure the volume and flow pattern of the Lewis River as applied both to ablation studies of the Barnes Ice Cap and to geomorphological problems, such as the relation between the silt content of melt water and erosion of glacial drainage channels, and (b) to provide the Geographical Branch with a nucleus of experienced and trained personnel for expanded research in these fields. The present paper may be regarded as a field manual describing the method in considerable detail for the use of glaciologists, geographers, and others whose knowledge of chemistry and physics is not extensive (see also British Standards Institution, 1961). Other methods of water-discharge measurement are outlined, the theory and procedures of the salt method are presented, and a list of the necessary field equipment is appended."

190. Schuster, J. C., 1964, Canal discharge measurements with radioisotopes. A Paper Presented at the Hydraulics Division Conference of the American Society of Civil Engineers, August 1964.

In experiments described in this paper, radioisotopes were used to make 65 discharge measurements in a 620-cfs. canal. Accuracies of about 97 per cent, or greater, were possible when a minimum straight length of 2500 feet was available for the mixing of the radioisotope and canal water. Diffusion coefficients were calculated to assist in the definition of a mixing length equation.

191. Seymour, Errol V., 1964, Tracing flow patterns in air using a radioactive gas. The Engineer, 218 (n. 5670):496-498.

"The development and testing of a technique for tracing air-flow patterns using Krypton-85 gas is described. It is shown that patterns may be traced in complicated geometries and in flows with velocities and diffusion rate high enough to make conventional methods, e.g. smoke tracing useless".

192. Skobunov, V. V., 1964, Measuring circuits for automatic recording of salt concentration in water flows. Translated from Izmeritel'naya Tekhnika, n. 2, February, 1964:28-39.

The author describes an instrument for the determination of salt concentration at various parts of a model simulating the dispersion of impurities in various aerodynamic systems. Platinum electrodes with diameters of 0. 3 mm. and lengths of 3 mm. were used to evaluate the concentrations. An unbalanced Wheatstone bridge, a rectifier, a 75-mV millivoltmeter type M252, and a 50-mV electronic recording potentiometer E-pp-09M2 formed the measuring circuit.

193. Wright, Robert R. and Michael R. Collings, 1964, Application of fluorescent tracing techniques to hydrologic studies. Journal of American Water Works Association, 56 (n. 6):748-754.

Recent U. S. Geological Survey experiments using Rhodamine B as a tracer and a fluorometer as a detecting instrument are described in this paper. Time-of-travel, rate-of-flow, and diffusion characteristics of streams with discharges varying from a few cubic feet per second up to thousands of cubic feet per second were studied.

194. Yotsukura, N., G. F. Smoot, and D. I. Cahal, 1964, Dispersion in open channel flow. American Society of Civil Engineers, Hydraulics Division Conference, Vicksburg, Mississippi.

By the use of velocity data from a 3.5 ft wide, 150 ft long channel and conductivity techniques, the authors determined the longitudinal dispersion coefficients for two different boundary roughness values and were able to correlate the Schmidt number and the Reynolds number for these flows. Data from other sources gave similar relationships but were quantitatively different. The differences in data were thought to be due to structural differences in the turbulence. Also, width-depth ratio was found to have a significant effect on the dispersion coefficient. In addition, it was observed that from a theoretical standpoint, the dispersion coefficient could be interpreted equally well by either the phenomenological concepts or the energy concept. In general, the results supported the numerical solution to the dispersion equation and its predictions as reported by Yotsukura and Fiering, 1964, ASCE 90 HY5:83-104.

195. Yotsukura, N. and M. B. Fiering, 1964, Numerical solution to dispersion equations. ASCE Journal, 90 (n. HY5):83-104.

These authors solved Taylor's dispersion equation by means of numerical approximations tracing the motion of a solute in two-dimensional channel flow with time. Their solutions showed that: (1) The longitudinal distribution of solute, either at a local or at a cross-sectional average level, approaches closer to the Gaussian pattern more and more as the dispersion progresses. (2) Transient distribution is characterized by a high degree of skewness caused by the convective transport which is related to the mean velocity distribution. (3) The dispersion coefficient can become constant even if the distribution is highly skewed, and it is not uniform in the depthwise direction. (4) The non-dimensionalized dispersion coefficient $K/n\mu^*$ varies with the function factor U/μ^* for a given velocity distribution.

196. Brinkworth, B. J. and E. G. Evans, 1965, A dilution method of flow-rate measurement using a light-scattering technique. Department of Mechanical Engineering, University College, Cardiff.

The Mechanical Engineering Department of the University College, Cardiff, has developed a method of flow-rate measurement based on the principle of injecting a suspension of polyvinyl-chloride particles into a pipe line. If a beam of light is then passed transversely through the pipe, the researcher can produce an instantaneous reading by integrating the concentration across a diamter. This method has proved to have the advantage of reducing error due to taking samples from different points in the pipe line, and it is the one best applied to transparent fluids in large pipes.

197. Clayton, C. G. and J. W. Webb, 1964, The use of turbulent dispersion to study the movement of underground streams. International Journal of Applied Radiation and Isotope, 16:171-176.

Theoretical and experimental investigations were conducted to determine the relationship between the principal hydraulic parameters and dispersion of tracers such as H^3. However, the derived equations are only applicable to the turbulent range ($R > 2 \times 10^3$).

198. Cobb, E. D. and J. F. Bailey, 1965, Measurement of discharge by dye-dilution methods. Surface Water Technique Series, U. S. Geologic Survey, Book 1, Chapter 14.

This manual describes the constant-rate injection and total-recovery methods of dye-dilution measurement. Dyes, equipment, field methods, and laboratory procedures are discussed, and the methods and procedures clarified by examples. Also, constant flow rate devices are described and illustrated, and many practical considerations in streamflow measurement are also explored.

199. Gebauer, von H. and S. Mueller, 1965, (German), Kontinuierliche Direktmessung radioaktiver ubstanzen in Wasser (The continuous direct measurement of radioactive matter in water). Die Atomwirtschaft, October 1962, n. 7 :487-491.

Four ways of introducing radioactivity detecting devices into water are described, and each discussed in detail.

200. Holley, E. R. Jr. and D. R. F. Harleman, 1965, Dispersion of pollutants in estuary type flows. Hydrodynamics Laboratory Report 74, Massachusetts Institute of Technology.

The author shows that the one-dimensional form of the mass balance equation can be obtained by spatially averaging the three-dimensional mass balance equation, a solution which indicates that there is a net transport associated with random concentration and velocity fluctuations. This net transport is shown to be diffusive in nature and therefore dependent on the concentration gradient. Some procedures used for modeling dispersion in estuaries are reviewed and criticized, and an analytical method is presented for the calculation of the dispersion coefficient for uniform oscillating flow of the type found in constant density regions of estuaries.

201. Martin, G. Q. and L. N. Johanson, 1965, Turbulence characteristics of liquid in pipe flow. A. I. Ch. E. Journal, January 1965:29-33.

Data on relative intensities and Eulerian scales of turbulence at the center of a pipe are reported in this paper. Water was pumped through at velocities ranging from 0.5 to 4.0 ft/sec (N_{Re} = 19,000 - 160,000), and the data gathered are compared with those reported for air. Previously, the Eulerian integral scales of turbulence for these Reynolds numbers had not been available. Correlations were also developed to relate the relative intensity of turbulence, the Eulerian and Lagrangian integral length scales of turbulence, and the eddy diffusivities, with the Reynolds number for fluid flow in the vicinity of the axis of smooth pipes.

202. Patterson, C. C. and E. F. Gloyna, 1965, Dispersion measurement in open channels. American Society of Civil Engineers, Proceedings 91 (n. SA 3):64.

In this paper, a summary is given of dispersion measurements made in the Colorado River and Pierce Canal. Equations are derived for the calculation of longitudinal and transverse dispersion coefficients from time-concentration data obtained from two-dimensional tracer fields. An empirical approach to the prediction of longitudinal dispersion coefficients was worked out with data obtained in flume experiments. The performance of this empirical formulation is compared to that of the deterministic formulae derived by Taylor and Elder. The tracers used in the Colorado River and Pierce Canal experiments were the fluorescent dyes, rhodamine B and fluorescien. The tracers were injected instantaneously at mid-depth near the center of the stream. A continuous recording fluorometer was used for obtaining the tracer time-concentration curve.

203. Watt, James P. C., 1965, Development of the dye-dilution method for measuring water yield in mountain watersheds. Unpublished Master's Thesis, Watershed Management Unit, Colorado State University.

For this study, the dilution method of flow measurement was used to obtain total yield information from small mountain watersheds. Three fluorescent dyes, Rhodamine B, Rhodamine WT, and Pontacyl Pink B, were utilized in the tests. Apparatus was designed and tested for continuous injection of the dyes and for discrete sampling of the stream water at 15 minute intervals. Then, the discrete samples were accumulated and mixed in a storage tank for the period of each experimental run. From the concentration of dye in the storage tank, the mean streamflow was estimated. Average yeild runs were made for periods offrom 13 to 92 hours. Both instantaneous and mean flow measurements gave an average error of +25% . However, the cause of the overestimate was not determined.

204. Wilson, Jr., James F., and William E. Forrest, 1965, Potomac River time-of-travel measurements. Reprinted from "Symposium on Diffusion in Oceans and Fresh Waters" held in 1964 at Lamont Geo. Observatory, Palisades, N. Y.

A recent study on the Potomac River of the measurement of time-of-travel of flow is described in this paper, the purpose being to illustrate the preparations and field operations. The purpose of obtaining time-of-travel information in this study was to collect data in order to warn the downstream dwellers against harmful contaminants and the duration of their danger.

VIII. INDEX BY AUTHORS

(This index by authors refers to the numbers of the references in the Chronological Bibliography. The index is arranged alphabetically according to author's last name. For each author's name the number of each reference and the year of publication are shown inside the parentheses.)

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(This list includes those papers which were not available for abstracting but which may have a bearing on the subject of tracer dilution measuring method)

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(This list includes those publications which have some general bearing on the problem of discharge gaging by the methods of dilution)

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XI. INDEX BY SUBJECTS

(This index is based on the abstracts in the chronological bibliography and not on the original text in the references. The purpose of this index is only to orient the reader toward the main references; there is no intention of showing full coverage of a subject by listing all references.)