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DISCHARGE MEASUREMENTS USING THE RADIOISOTOPE VELOCITY, INTEGRATED SAMPLE, DILUTION, AND TOTAL COUNT METHODS AT FLATIRON POWER AND PUMPING PLANT COLORADO-BIG THOMPSON PROJECT

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Discharge Measurements Using the Radioisotope Velocity, Integrated Sample, Dilution and Total-Count Methods at Flatiron Power and Pumping Plant Colorado-Big Thompson Project

by

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FOREWORD

This report, a product of the Research Division, is issued as part of a contract between the U.S. Atomic Energy Commission and Bureau of Reclamation. The work was cooperatively done by the Hydraulics and Chemical Engineering Branches, directed by H. M. Martin and L. O. Timblin, Jr.

The study was materially assisted by the work of G. A. Teter, U. J. Palde, R. A. Dodge, of the Research Division, and the personnel operating and maintaining Flatiron Power and Pumping Plant under the supervision of Messrs. G. R. Highley and L. Willits.

ABSTRACT

Radioisotope techniques and equipment are being developed to improve methods for measuring flow rate in high-head turbines and pumps. A series of discharge measurements were made in 1968, at Flatiron Powerplant near Loveland, Colo, to evaluate techniques and equipment. Measurements were made on a 6000-ft-long, 6-ft-dia penstock at a discharge of 300 cfs. Thirty-seven injections of radioactive Bromine-82 were made for discharge measurements by the velocity method, 17 for the integrated-sample method, and 8 for the dilution method. These injections enabled computation of 33 discharges by the velocity method, 26 by the integrated sample, 45 by the dilution method, and 34 by the total-count method. A 4-point injection system, 45 deg from the vertical and horizontal centerlines of the pipe, was used for most measurements. Mixing lengths ranged from 36 to 919 pipe diameters. Mixing lengths of 100 pipe diameters produced the same order of accuracy as mixing lengths of 919 diameters. Studies are continuing to increase measurement accuracy using pipe lengths as short as 30 pipe diameters.

DESCRIPTORS—/ hydraulics/ physics/ *water measurement/ penstocks/ field tests/ *radioisotopes/ *tracers/ pump turbines/ turbines/ water sampling/ injectors/ pipelines/ fluorometry/ radioactivity techniques/ *discharge measurement/ Colorado
IDENTIFIERS—/ Flatiron Powerplant, Colo/ velocity method/ total count method/ Atomic Energy Commission/ dilution method/ *mixing length

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SYNOPSIS

The Atomic Energy Commission, AEC, and Bureau of Reclamation are cooperating in a research program to establish feasibility and develop procedures for measuring discharge through high-head turbines and pumps using radioisotopes. The results of the development of techniques for making precision discharge measurements are summarized in the following paragraphs.

Detailed results of the progress in Phases I and II through September 1966 were reported to the AEC in TID-23737, "Discharge Measurement Using Radioisotopes in High-head Turbines and Pumps." Phase III of the joint program was reported by the Bureau to the AEC in Report No. TID-25177, "Discharge Measurements Using Radioisotopes in High-head Turbines and Pumps at Flatiron Power and Pumping Plant, Colorado-Big Thompson Project."

Phase IV of the program was begun in April 1968. Field testing of prototype injection and sampling systems was continued at the Flatiron Power and Pumping Plant. Three series of measurements were made to compare the relative accuracy of the radioisotope-velocity, integrated sample, dilution, and total-count methods of measuring 300 cubic feet per second in a 6,000-foot-long penstock having diameters ranging from 7 to 6 feet, Figure 1.

Thirty-seven separate injections of radioactive Bromine-82 were made for discharge measurements by the velocity method, 17 for the integrated-sample method, and 8 for the dilution method. These injections resulted in 33 discharges computed by the velocity method, 26 by the integrated sample, 45 by the dilution method, and in addition 34 were computed by the total-count method. A 4-point injection system, 45° from the vertical and horizontal centerlines of the pipe, was used for the majority of the measurements, Figure 3.

Injections were made through 1/4-inch tubes restricted by 1/64-inch orifices. The tubes were inserted into the pipe through orifice plugs provided during construction for pressure measurements in the penstock. The 1/4-inch size of the tubes permitted injection of the tracer at the wall of the pipe and at distances of 0.04 and 0.19 of the radius from the pipe wall. Within the bending strength of the 1/4-inch tubes, the injection point was changed to determine the effect on mixing of the radial location of the injection point. A gas-pressured system was used for injection of the radiotracer.

Discharge measurements were made in pipeline lengths of 36.5 diameters of 7-foot pipe, 105 diameters of 7- and 6.5-foot pipe, and 919 diameters of 7-, 6.5-, and 6-foot pipe. Of the 5,632 feet of pipe available for measurements, 4,400 feet were 6 feet in diameter.

Detectors were strapped to the outside of the pipe to measure the tracer passage for the velocity method of flow rate computation.

Sampling tubes for the dilution method were located 36.5 diameters downstream from the injection cross section in four access pipes 90° apart on the circumference of the penstock. These access pipes were in the same angular relation to the centerlines as the injection tubes. Two sample tubes located on a vertical centerline, one at 0.04 of the radius and the other at 0.54 radius in the 6.5-foot pipe, were installed in a manway 105 diameters from the injection system.

The two locations at 36.5 and 105 diameters were chosen because previous studies indicated that the mixing lengths would approach the minimum that may be used for multipoint injection and a multiple sample of the flow and a mixing length about the minimum for single-point injection and sampling.

A third sampling point was a 1/4-inch hole at the inlet to the turbine, a distance of 919 diameters from the injection.

Integrated and/or continuous flow samples were taken from the pipeline for counting, depending on the method or combination of methods being studied. Discharge measurements were made independently with the spiral case flowmeter of the turbine.

Tables 1 and 2 summarize the average deviation between the velocity, integrated sample, dilution, and total count radioisotope methods, and the spiral case flowmeter. In general, the average deviation is less than ±2 percent but one of the values for the total count exceeded the spiral case flowmeter by 3.6 percent, one for the dilution by 3.4 percent, and one for the velocity by 2.4 percent. The measurements indicate that in the majority of the comparisons the computed radioisotope discharge exceeds the discharge obtained from the spiral case flowmeter. This tendency has been noted for both open-channel and closed-conduit studies by the Bureau and from information on comparative measurements published by others.[1]

[1]Spencer, E. A. and Winternitz, F.A.L., 1964, Comparative Flow-measurement Tests at Finlarig Station, Department of Scientific and Industrial Research, NEL, Report No. 148.

Table 1

MEASUREMENTS BY THE VELOCITY, INTEGRATED SAMPLE, AND TOTAL COUNT METHODS

	Velocity			Integrated sample		Total count
Number of measurements	8	17	8	13	13	14
	(diameters to first counter)					
Mixing length	14 dia.	45 dia.	82 dia.	105.5 dia.		919 dia.
Location of sample	(22 diameters between counters)			0.54R	0.04R	side
Average deviation $(Q_{sc}-Q_R/Q_{sc}) \times 100$ percent	+1.5	-1.7	-2.4	-1.5	-1.0	-1.3
Standard deviation σ percent	1.6	1.8	1.2	2.7	2.7	0.8

Q_{sc} = Spiral case flowmeter indicated discharge

Q_R = Radioisotope indicated discharge

Table 2

MEASUREMENTS BY THE DILUTION AND TOTAL COUNT METHODS

	Dilution								
	Integrated sample			Scaler record			Total count		
Sample location	4 points	0.54R	0.04R	0.54R	0.04R	Pwr Plnt	0.54R	0.04R	Pwr Plnt
Mixing length	36.5 dia.	105.5 dia.		105.5 dia.		919 dia.	105.5 dia.		919 dia.
Number of measurements	7	8	8	7	7	8	7	7	7
Average deviation $(Q_{sc}-Q_R/Q_{sc}) \times 100$ percent	+1.9	-0.3	-0.6	-1.8	-3.4	-1.3	-1.6	-3.6	-0.4
Standard deviation σ percent	2.6	1.8	1.9	1.0	2.4	1.2	1.7	2.2	1.6

Included in the results for each measurement series is an estimation of the errors in the measurements. One estimate is based on a summation of the standard deviation of determining the discharge from the spiral case flowmeter calibration curve and the standard deviation of the errors possible in the radioisotope methods. The second estimate is the summation of the errors used for computing the standard deviation for the radioisotope method and two standard deviations (95% confidence level) of measurement for the spiral case manometer. The results of the comparisons are shown in Tables 4, 6, 8, 10, and 13 and Figures 11, 15, 25, 26, 27, and 28. Mixing lengths of 100 pipe diameters or more appear to produce the higher accuracies of measurements.

Nearly all of the measurements of Phase IV were made from injections near the wall of the pipe and from four points in the cross section. With the exception of the sample taken at 36.5 diameters all sampling of the flow was through single orifices. At the 36.5-diameter distance, four holes 90° apart in the same cross section were connected to withdraw a single sample. The results of the discharge measurements are shown on Figure 25 and Table 7. Discharges computed from measurements at both the 36.5 and 105.5 diameters show about the same deviation from the spiral case flowmeter. This agreement would indicate that for the multiple injection a shorter mixing length can be used if multiple samples are blended into one sample or are averaged from multiple samples.

For all of the radioisotope methods there are measurements that exceed the error that was estimated for presently used procedures and equipment. A critical review may reveal ways of eliminating or improving some of the steps being used in preparation of calibration solutions and the radioisotope fraction being injected for the measurement. Such improvement would reduce the total error to be expected in a measurement.

Improvements can be made in the counting of the radioisotope water mixture extracted from the pipe for the discharge measurement. This improvement could be accomplished by counting the mixture for longer periods to increase the statistical accuracy, better shielding of the detectors, and increasing the ratio of the sample to background count rate. A temperature effect on the detectors was noted during the dilution measurements. Subsequent studies on the counting system gave the order of magnitude of the effect. The temperature effect and other counting irregularities will be analyzed in an effort to find reasons for measurements deviating beyond the expected error.

INTRODUCTION

Four of five proposed phases of the program have been completed with the results of Phase IV published in this report. The results of Phases I and II were reported to the AEC by the Bureau in AEC Report TID-23737, "Discharge Measurements Using Radioisotopes in High-head Turbines and Pumps," September 1966. Phase III results were furnished to the AEC by the Bureau in Report No. TID-25177, "Discharge Measurements Using Radioisotopes in High-head Turbines and Pumps at Flatiron Power and Pumping Plant, Colorado-Big Thompson Project."

Laboratory and field measurements of Phases I, II, and III gave good information on lengths of pipe required for natural turbulence to mix the pipe flow and tracer injected into the penstock. These studies showed that injections at a selected point between the center and side of the penstock did not produce a significant reduction in the mixing length over that for a centerline injection. A 310-diameter mixing length for a centerline injection into water flowing about 4.5 feet per second (1.4 mps) did not apparently result in satisfactory mixing for a discharge of about 130 cfs in a 6-foot-diameter pipeline. Measurements made after the tracer had mixed for 645 diameters deviated from flowmeter measurements by an average of about +1.2 percent, about one-half that for the 310 diameters.

Studies on a pump discharging about 290 cfs in the same plant showed that the scale and intensity of the turbulence was increased by the pump. A mixing length of 164 and 755 diameters in the 8-foot pump line appeared to be satisfactory for a tracer injection near the sidewall into a water velocity ;of about 6 feet per second (1.8 mps). Injections were made both upstream and downstream from the pump. The average deviation between a flowmeter and the radioisotope method was +0.6 percent at 755 diameters and about -2.0 percent for 164 diameters.

In general, the discharges measured by the radioisotope method varied over a larger range than desirable. The exact causes of the variations could not be readily determined but were attributed to anomalies in the radioisotope techniques of sampling and/or counting. This conclusion formed the basis for the emphasis of the program in Phase IV. Equipment and instruments were modified and techniques of application were revised before field discharge measurements were again made at Flatiron Power and Pumping Plant.

POWERPLANT FACILITIES

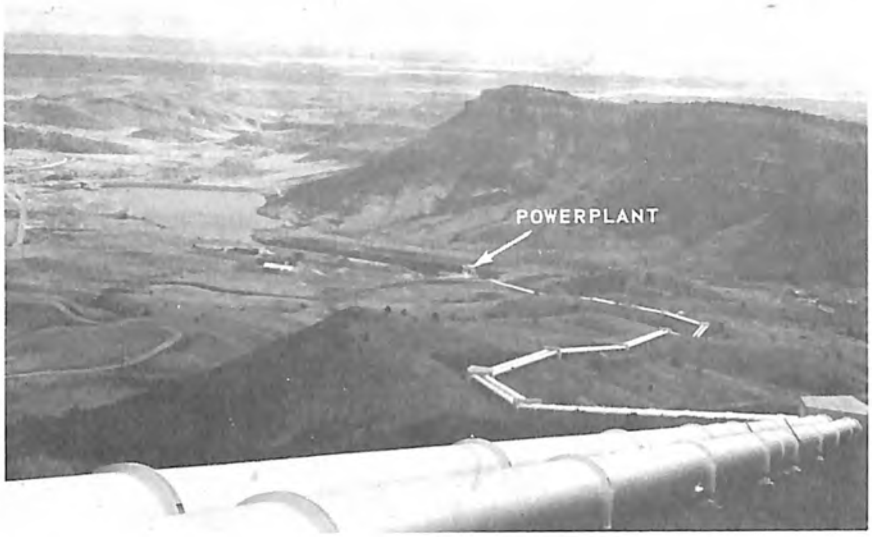
Flatiron Power and Pumping Plant, Figure 2, is located about 55 miles north of Denver, 14.5 miles east of Estes Park, Colorado. The plant develops power from regulated flows in a 1,110-foot fall from Pinewood Reservoir to Flatiron Afterbay Reservoir, Figure 3. Water flows through a pressure tunnel to a wye transition and two 84-inch butterfly valves at the entrances to the penstocks. The penstocks, Figure 1, about a mile long and ranging from 7 to 6 feet inside diameter, are exposed for most of the length on the hillside.

Manways, having a diameter of 20 inches, were provided during construction for access to the pipe interior at intervals of about 275 feet. The manways were located on the top of the penstock and at a clockwise angle of 135° viewing the penstock in the direction of flow.

Study of the penstock profile and alinement showed that a good measurement section began about 148 feet (21 pipe diameters) downstream from the butterfly valves, Figure 3. Four 1/4-inch piezometer plugs had been installed in the pipe at 45° from the vertical and horizontal centerlines. A second set of piezometers had been installed 210 feet (30 diameters) downstream from the first set. An additional four access pipes were available at 36.5 diameters from the first set of piezometers.

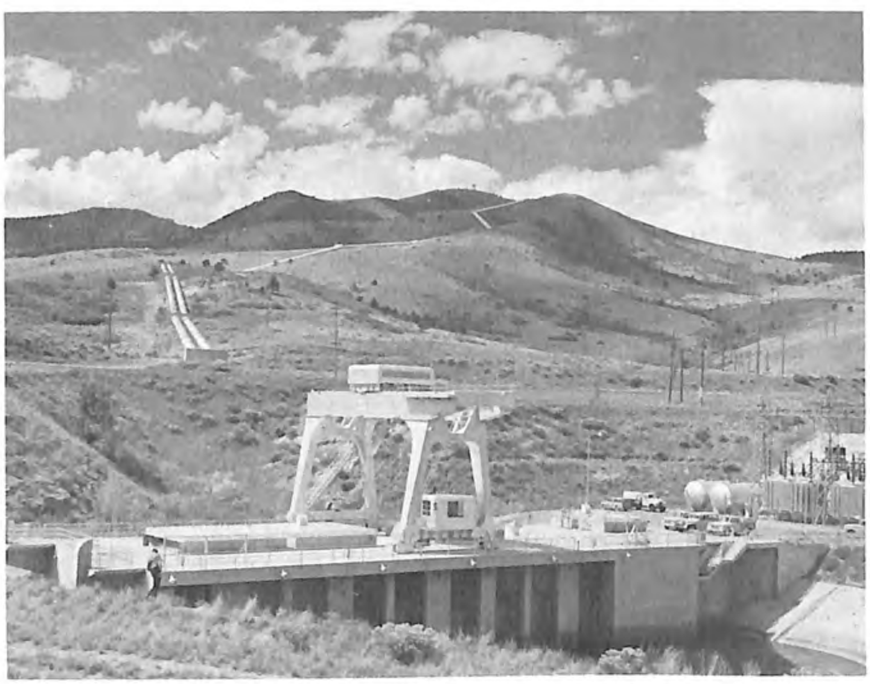
Several manways were located along this straight section of penstock. One manway, located a distance of 105.5 diameters (68.9 diameters of 7-foot pipe and 36.6 diameters of 6.5-foot pipe) was chosen for installation of a sampling system, Figure 4. Thus, in this particular length of pipe, mixing lengths of 30, 36.5, and 105.5 pipe diameters were available for mixing the tracer and flowing water. One more sampling station was established at the inlet to the turbine, about 919 diameters from the first set of piezometers.

Tracer injecting and sampling systems, to be described later in the report, were installed as needed for the discharge measurements.



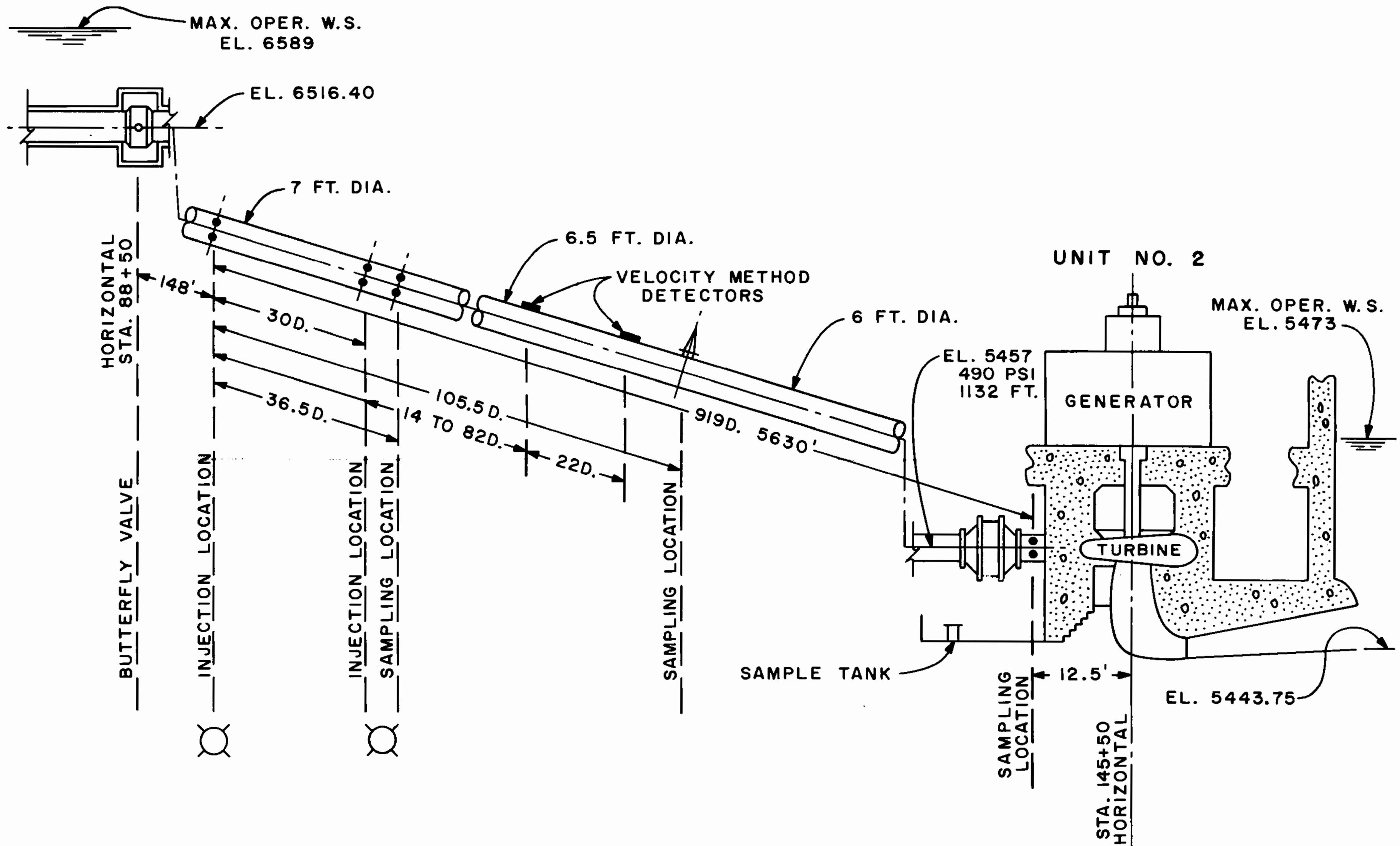
Flatiron Powerplant Penstocks—Butterfly Valve House Behind Camera—Radioisotope Discharge Measurement Section in Foreground on Right Hand Penstock. Photo P245-D-60413NA

Figure 1



Flatiron Power and Pumping Plant and Channel to Afterbay Reservoir. Photo P245-700-1502A

Figure 2



FLATIRON POWER PLANT AND PENSTOCK SECTION

INJECTION AND SAMPLING LOCATIONS

FIGURE 3

Sampling Equipment Installed at Manway for Integrated Sample and Dilution Methods of Measurement. Photo P245-D-63688NA

Figure 4

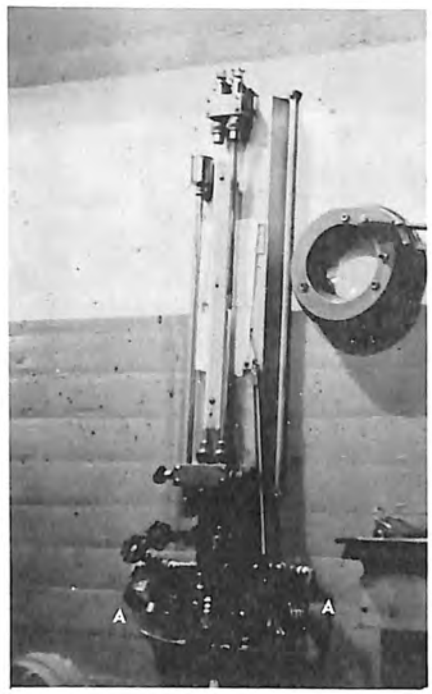
DISCHARGE MEASUREMENTS

Spiral Case Flowmeter

An elbow-type flowmeter (named a spiral case flowmeter) was installed on the turbine during construction. This flowmeter was used as an independent measure of discharge and indicator of the steadiness of flow in the penstock. The discharge indicated by the flowmeter was compared to the discharges measured by the radioisotope methods to determine the repeatability of the radioisotope measurements.

A calibration of the flowmeter was performed in 1954 by the salt-velocity method of discharge measurement. Before conducting the radioisotope measurements in 1967 and 1968, the pressure orifices in the spiral case were inspected and cleaned to provide the smooth flow surface of the calibration.

The flowmeter was designed to produce a differential of about 7 inches of mercury for a turbine discharge of 500 cfs. A mercury U-tube manometer was connected across the pressure orifices, Figure 5. To minimize the pressure fluctuations from the flowmeter, two 1/16-inch damping coils were placed in the lines to the manometer.



Mercury Manometer for Turbine Spiral Case Flowmeter (a) Damping Coils. Photo P245-D-63695NA

Figure 5

After air purging and adjusting the zero of the manometer, periodic readings (15-second intervals) of the differential were manually recorded while the radiotracer was passing through the penstock. Segments of these readings corresponding to the period of tracer sampling were used to determine the flow in the pipe.

Radioisotope—Velocity Method

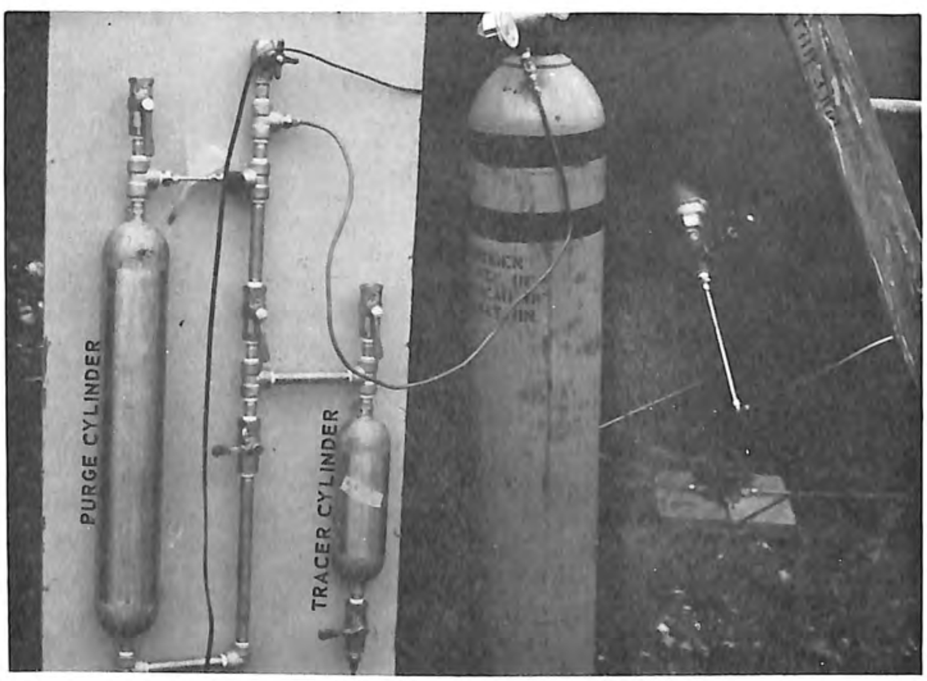
Procedure.—The tracer-velocity method of discharge measurement uses the principles of the salt-velocity method. A cross section of the pipeline is chosen for the injection of the tracer. Downstream, the diameters in a length of the pipe are measured to determine the volume. Detectors are located at the beginning and the end of this known volume. A discharge measurement is made by injecting a pulse of tracer and then measuring the time required for the tracer to pass between the two detectors. A discharge may then be calculated from the measured pipe volume and the time computed from the record of the tracer passage

$$\text{Discharge } Q = \frac{\text{Volume (area times length)}}{\text{Time}}$$

Three mixing lengths, 14, 45, and 82 diameters of pipeline were used for the measurement series, Figure 3.

A pulse injection system was constructed of 1,800-psi sample cylinders and stainless steel tubing, Figures 6 and 7. A 1-liter cylinder was used to hold the radiotracer before injection into the penstock. A 3.78-liter cylinder was used to hold water to purge the tracer cylinder after injection. The piping was arranged and valved to apply pressure from a 2,000-psi nitrogen bottle to the tracer cylinder and then to the water purge cylinder for rinsing. Flexible and rigid stainless steel tubing carried the tracer solution to the injection manifold. The manifold contained four outlet ports to the injection tubes inserted into the penstock. Radiotracer was injected at the wall or 8 inches from the wall. Two radiation detectors were strapped in contact with the steel outer surface of the penstock. (Type shown in Figure 8.) The detectors or the injection location were moved to obtain the desired mixing length.

The passage of the tracer was recorded in digital form on printed or magnetic tape by instrumentation assembled in a mobile nuclear laboratory, Figures 9 and 10. A dual-channel scaler containing two 5-decade fast readout scalers was used to totalize the detected radiation emissions. The instrument can be used manually as a regular scaler or, as in these measurements, as an automatic instrument feeding data to the recorders. When the time or count had reached a preset value, the counts accumulated were transferred to a buffer storage, the scalers reset, and restarted within 10 microseconds. The digital data from the storage was then transferred to the tape printer.

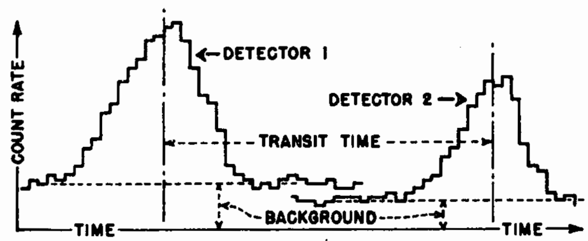


Pulse Injection System for Radiotracer—Valves in Position for Filling Cylinders—Injection Tube Inserted Through Pipe Wall. Photo P245-D-63687NA

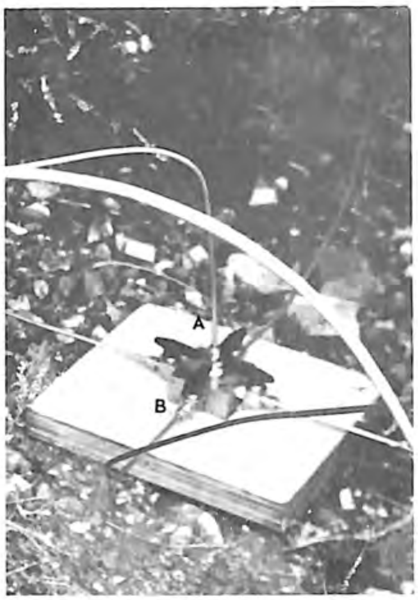
Figure 6

Input data to the dual-channel scaler was simultaneously recorded on magnetic tape. The recorder, a high-speed, high-fidelity memory unit, was designed for radiation measurements. A choice of speeds for both recording or playback permits a study of the data for selected time Intervals. This playback capability was used in reproducing the concentration-time curve of the radiotracer passing the two detectors.

The transit time of the tracer from the first to the second detector was computed as the time between the centers of area of the two tracer curves (schematically shown below).

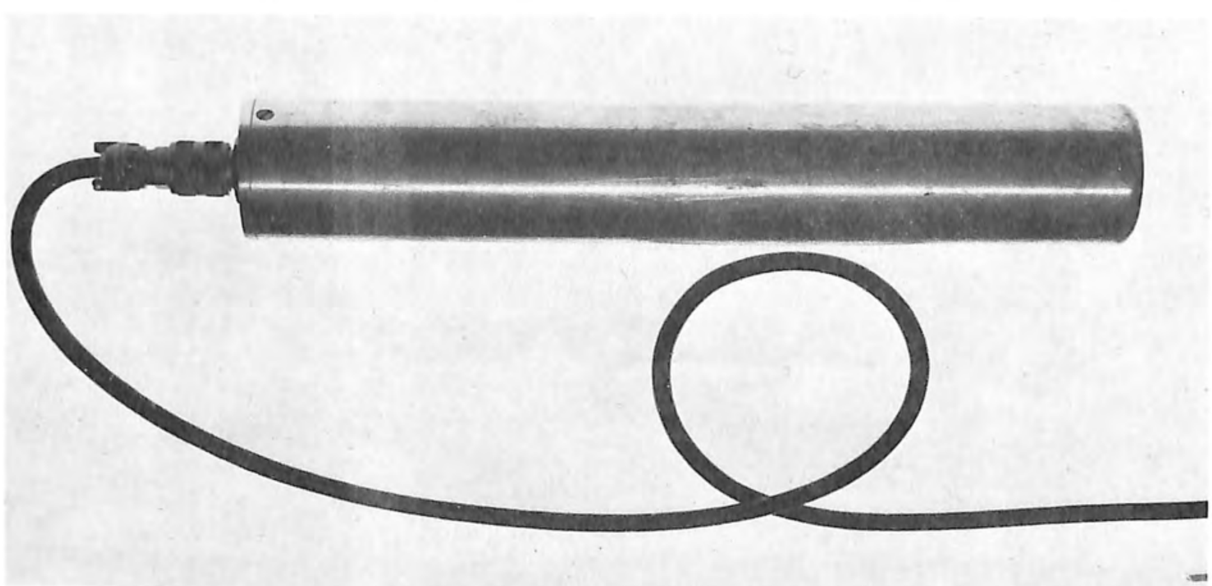


CONCENTRATION – TIME CURVES



Injection Manifold (a) Tube from Tracer Cylinder (b) Ball-valves at Outlet Ports. Photo P245-D-63799

Figure 7



Radiation Detector used for Discharge Measurements by Tracer-Velocity Method and in Sample Tanks. Photo PX-D-64664

Figure 8

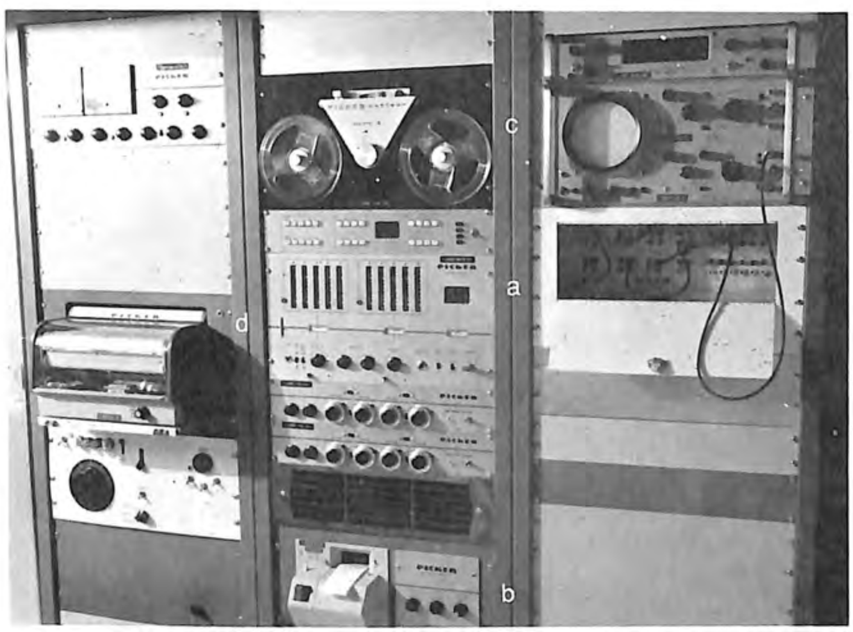
Mobile Nuclear Laboratory. Photo P245-D-63806

Figure 9

The center of area and the time difference was processed by computer from the digital data. The computer program, essentially a process of integration, accounts for the average background radiation in computing the center of area.

Distances of 22.1 and 20.6 pipe diameters of 6.5-foot-diameter pipe were used for the measurement series. This distance provided a transit time between detectors of about 21 seconds at a 300-cfs discharge.

The pipe volume between the detector positions had been measured for one of the two selected sections at the time of the turbine tests. Thirty diameter measurements averaged 0.12 percent less than the 6.5-foot designed diameter. Inspection of the penstock before the radioisotope tests showed the interior of the pipe to be clean and thus no change in volume. The volume of the second test section



Radiation Counting and Recording System Installed in Mobile Laboratory (a) Scaler (b) Printer (c) Magnetic Tape (d) Analog Recorder. Photo PX-D-64665

Figure 10

was computed from the ratio of the nominal to measured volume of the acceptance test section. An absolute value for the volume of the test section was desirable but not a critical requirement because the study involved the repeatability of the radioisotope measurements. For a selected test length and measurement series the pipe volume is a constant in the computation. Errors in the computed volume would affect the results in comparisons of discharge measured in different sections of the pipeline and when compared to another method.

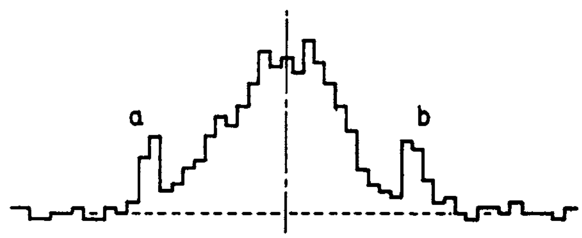
Results of measurements.—Deviations larger than the desirable 1 percent or less occurred between discharge measurements by the radioisotope-velocity and flowmeter methods. Differences ranging from about a -5 percent to a +4 percent occurred in the series of 33 measurements, Table 3. One series of 8 measurements indicated the flowmeter discharge was an average of 1.5 percent higher than the radioisotope method for a mixing length of 14 pipe diameters. In a second series of 17 measurements and a mixing length of 45 diameters, the discharge measured by the radioisotopes averaged 1.7 percent more than the flowmeter. In the last series of 8 measurements at a mixing length of 82 diameters the radioisotope method exceeded the flowmeter by 2.4 percent.

An error analysis of the method showed an estimated standard deviation of ±1.7 percent and a total possible error of about ±2.8 percent. A study of this data, Table 4 and Figure 11, show larger than expected deviations between the radioisotope and flowmeter discharges. In the first series 50 percent of the deviations were larger than 1.7 percent, in the second 59 percent were larger, and in the last series 50 percent were larger. In each of the series more measurements than desirable exceeded the expected total possible error, Table 4.

There appear to be two major causes of the deviations: (1) a single detector was used at each sampling station for recording the tracer passage; and (2) the difficulty in computing the center of areas of the recorded tracer count rate.

Short mixing lengths between the injection and detection points were used in the first and second series of measurements. A uniform mixing of tracer and pipe flow was not obtained and was evident in the irregularity of recorded count rate on a single detector. Because of the nonuniform mixing, detectors located at different stations along the pipeline may not receive the same amount of radiation as the tracer-water mixture passes the detectors.

The nonuniform mixing caused irregularities in the detection of the recorded concentration. These irregularities in turn made difficult the computing of the center of area of the change in concentration recorded as the count rate. Large count rates (a and b schematically shown) near the beginning or the ending of the recorded concentration, had an undue influence on the center of area. These isolated large values occurred in many of the recorded traces and in the digital data on printed tape. The accuracy of the computed discharges may have been decreased by these isolated values as well as those occurring near the peak count rate.



These irregularities also occurred for the longer mixing length of 82 pipe diameters. Although the tracer-water mixture was diffused over a greater length of penstock and the increase and decrease of concentration more uniform, isolated larger count rates occurred and may have affected the computation of the center of area.

Multiple detectors, three or more at each of the two cross sections connected to a single scaler, would improve the averaging of the concentration of the tracer-water mixture. The larger number of detectors would minimize the count rate fluctuations, could possibly aid in reducing the quantity of radioactive material required and provide count rate data for reliable computation of the center of area. A detector with a 2- by 3-inch disc scintillation crystal and photomultiplier, Figure 12, became available after completion of these measurements. A detector configuration of this type applied to the tracer-velocity method would improve the accuracy of the measurement by providing a greater counting yield per unit of tracer activity injected.

Integrated Sample Method

Procedure.—A known amount of radiotracer was

Table 3

DISCHARGES MEASURED BY RADIOISOTOPE-VELOCITY METHOD

Measurement number		Discharge cfs Spiral case Q_{sc}	Discharge cfs Radiosotopes Q_R	Percent deviation $\frac{Q_{sc}-Q_R}{Q_{sc}} \times 100$	
	14 pipe diameters to first detector				
1–4	Measurements lost because of data overlap				
5	Pipe volume	287	279	+2.8	Average
6	between detectors	286	281	+1.9	+1.5
7		284	286	-0.9	σ
8	4,422 cu ft	284	272	+4.1	±1.6
9		284	285	-0.6	
10		281	277	+1.7	
11		284	283	+0.7	
12		284	279	+2.1	
	45 diameters to first detector				
13	Pipe	283	293	-3.3	Average
14	Volume	283	293	-3.1	-1.7
15	5,956 cu ft	284	288	-1.3	
16		284	282	+0.9	
17		284	288	-1.3	σ
18		301	307	-2.1	±1.8
19		299	312	-4.3	
20		300	306	-2.0	
21		300	311	-3.6	
22		301	313	-4.0	
23		302	297	+1.7	
24		300	306	-2.0	
25		296	302	-2.1	
26		298	299	-0.4	
27		298	306	-2.6	
28		297	293	+1.4	
29		295	295	0	
	82 diameters to first detector				
30	Pipe	298	312	-4.8	
31	Volume	300	303	-1.0	Average
32		300	308	-2.6	-2.4
33	4,422 cu ft	300	308	-2.7	
34		300	304	-1.3	σ
35		298	302	-1.3	±1.2
36		297	308	-3.6	
37		297	302	-1.5	

Table 4

RADIOISOTOPE-VELOCITY METHOD

Estimated Errors in the Discharges Computed for
Spiral Case Flowmeter and Radioisotope Methods

Discharge Measurements

(Distance between counters 22 diameters)

Number of measurements	Mixing length—injection to first counter (diameters)	Percent deviation $Q_{SC}\text{-}Q_R/Q_{SC} \times 100$	
8	14	4 > 1.7%	50% < 1.7%
		1 > 2.8%	87% < 2.8%
17	45	10 > 1.7%	41% < 1.7%
		5 > 2.8%	71% < 2.8%
8	82	4 > 1.8%	50% < 1.8%
		2 > 2.8%	75% < 2.8%

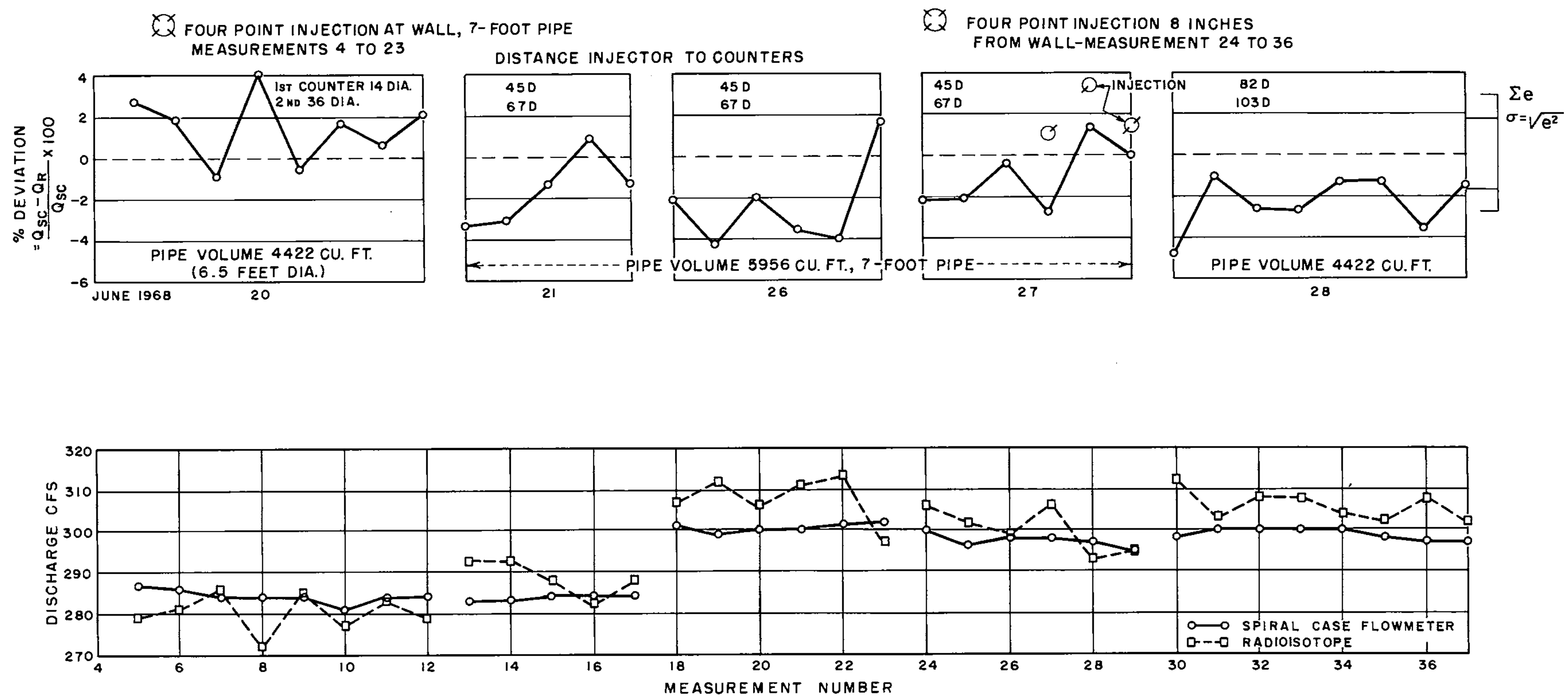
Standard deviation

(a) Flowmeter manometer reading = ±0.8%
(b) Volume and time (Q=V/T) = ±0.9%
±1.7%

Total possible error

(a) Manometer (2σ) = ±1.6%
(b) Volume and time (Σe) = ±1.2%
±2.8%

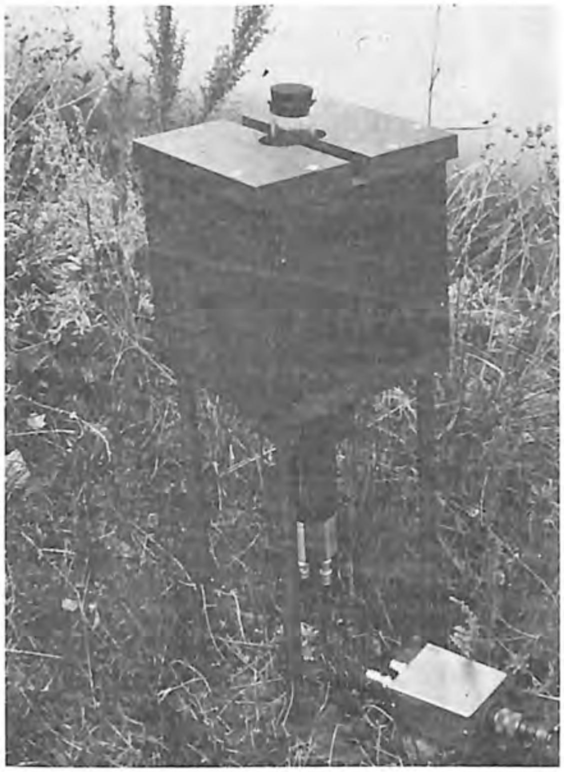
See Figure 11



DISCHARGE MEASUREMENTS BY RADIOISOTOPE - VELOCITY METHOD
TURBINE UNIT NO. 2

FLATIRON POWER AND PUMPING PLANT

FIGURE 11



Radiation Counting Flask in Shield-Disc Scintillation Counter and Photomultiplier Mounted Below Flask in Shield Opening. Photo P245-D-63693NA

Figure 12

injected into the penstock in 18-26 seconds from the gas-pressured system, Figure 6. Samples of the tracer-water mixture were taken at a constant outflow rate from two points in the flow cross section 105 pipe diameters from the injection. The samples were collected in plastic containers as the pulse of tracer passed the sampling point, Figure 13. Samples were obtained from points 0.54 and 0.04 of the radius from the pipe wall, Figure 14.

The constancy of the flow rate from the sampling tubes was indicated by a study of the pressure at the entrances to the tubes. A strain-gage-type pressure transducer was connected near the entrance to the sample tube. Pressures (of nearly a constant amount) were measured and recorded for a range of sampling rates.

Three large samples were obtained for each injection from each point; a sample of the background before arrival of the tracer, a sample of the tracered pipe flow, and a background sample after tracer passage. Time was measured accurately for each of the three sample quantities by means of an electrically driven clock. Monitoring of the tracer-water mixture and samples was assisted by the radiation counting in a sample tank used for a total count measurement of the discharge.

The samples were counted in glass flasks placed in a shielded counting chamber, Figure 12. A 2- by 3-inch NaI(Tl) disc scintillation crystal optically bonded to a photomultiplier was centered at the bottom of the flask and shield. Thus the samples could be field counted by using the equipment in the mobile laboratory or in the powerplant. Both methods were used in the course of the discharge measurements:

Discharges were computed from the basic equation

$$Q = \frac{A}{\int^T C_2 dt}$$

in the form

$$Q = \frac{C_i v_2 n \, (R_s - R_B)}{(R_u - R_B) \, C_s \, T}$$

where

C_i = concentration of diluted shipment (approximately 1 liter)

v_2 = buret volume

n = number of buret volumes

$C_i v_2 n$ = A (amount of tracer injected)

C_s = αC_i (Sample used as standard)

σ = fraction of dilution C_i

R_s = count rate for standard sample*

R_B = background count rate

R_u = integrated sample count rate

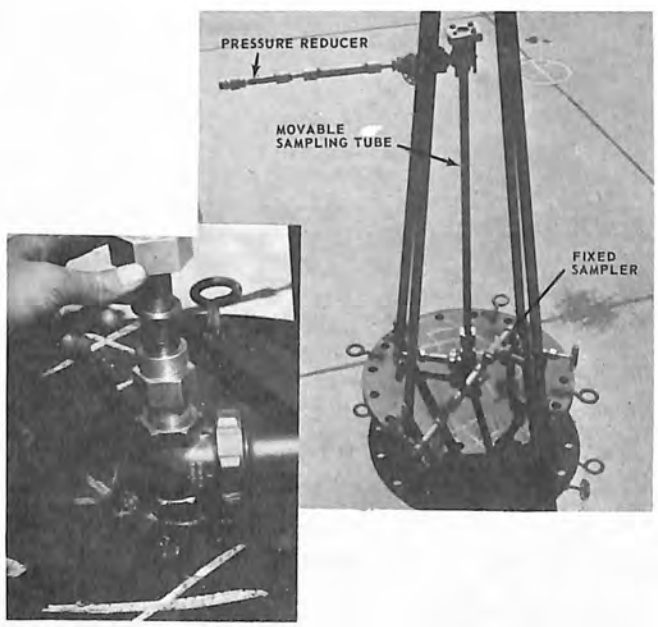
T = time of collecting integrated sample

$\frac{R_s - R_B}{C_s}$ = calibration factor for counting system

*All count rates corrected for radioactive decay

Mobile Nuclear Laboratory at Sampling Point 105 Diameters from Injection—Sample Containers and Timer on Platform. Photo P245-D-63691NA

Figure 13



Stuffing Box for Movable Sampler. Photo P245-D-63690NA

Arranagement of Piping for Movable and Fixed Position Sampling Tubes. Photo P245-D-63689NA

Figure 14

With the exception of preparing the amount of tracer A and the standard C_s in the laboratory, all radiation measurements for the discharge computations were performed at the field site.

In conjunction with the integrated-sample method, a discharge measurement was made at the turbine by the total-count method.

A later section of the report describes these measurements and those obtained by total-count measurements during the study of the dilution method.

Results of measurements.—Twelve of the 26 discharge measurements made by the integrated sample method deviated by amounts larger than expected from the error analysis, Table 5 and Figure 15. The measurements that deviated did so in general for both the 0.54R and 0.04R locations for the same measurement, e.g., Measurements No. 7, 9, 14, and 16. For these measurements the sign of the deviation was the same. In Measurements No. 5, 10, 13, and 15, one large deviation occurred at one of the sampling locations and a smaller deviation occurred at the other sampling location. The signs of these deviations were not always the same.

Those measurements deviating in the same direction and in approximately the same amount would appear to have been caused by an error in the measurement of the injected tracer or in system calibration. The latter seems the least likely because of the occurrence within a group in the same test series for which two or more standards are measured. The fact that the deviations are approximately the same amount would indicate the problem was not mixing.

For the measurements deviating in larger values but at only one of the two positions in the sampling cross section, the mixing of tracer and flowing water or the radiation counting may have been the source of error.

The mean deviation for discharges measured at the 0.54R sampling point was -1.5 percent and at the 0.04R point -1.0 percent. The range of deviations was large, from a +2.6 percent to a -7.9 percent. Of the 13 discharges computed from radioactive samples taken from the 0.54 radius location 39 percent were less than the estimated standard deviation of ±1.8 percent and 85 percent were less than the estimated total possible error of ±4.2 percent, Table 6. At the 0.04R location 54 percent were less than ±1.8 percent and 85 percent were less than the total error.

The accuracy of the integrated-sample method probably can be increased by improvements made in tracer handling and radiation counting procedures. The ultimate accuracy may be limited by the pulse type of injection used for the method. A sampling of the pulse of tracer-water mixture from a single point may not provide a satisfactory integration of the flow for an accurate discharge measurement. The simplicity of applying the method suggests that additional study should be made to improve the accuracy.

Study of Diffusion with Fluorescent Dye

Purpose.—The deviations between simultaneous discharge measurements from samples taken in the same cross section of the pipe indicated that the cause may have been inadequate mixing of the tracer and flowing water. Fluorescent dyes were used to measure the degree of mixing because no means were readily available for monitoring 1/4-inch streams of radiotracered-water to show small and rapid fluctuations in concentration.

Procedure and equipment.—A constant rate injection and constant rate of sample withdrawal were used to explore the degree of mixing in the flow. A diaphram-type pump operated at 230 strokes per minute from 110-volt, 60-Hz supply line was used to force the dye into the flow, Figure 16. The capacity of the pump was 9,000 milliliters per hour and the flow rate could be adjusted by changing the stroke length of the piston driving the diaphram. A buret filled with about a 10 percent solution of fluorescein dye in water was used to supply the pump and to determine the injection rate. The buret scale and a stopwatch were used to measure the pumping rate.

The discharge of the pump was connected to the four-way injection manifold and then to the four injection points in the penstock, Figure 16. Dye was thus added to the flowing water in the same manner as the radioisotope but at a rate reduced from about 50 milliliters per second to 2 milliliters per second.

Samples were withdrawn from the penstock at the 105-diameter location through the movable and fixed sampling tubes, Figure 17. A fluorometer was attached to each tube and the flow rate was

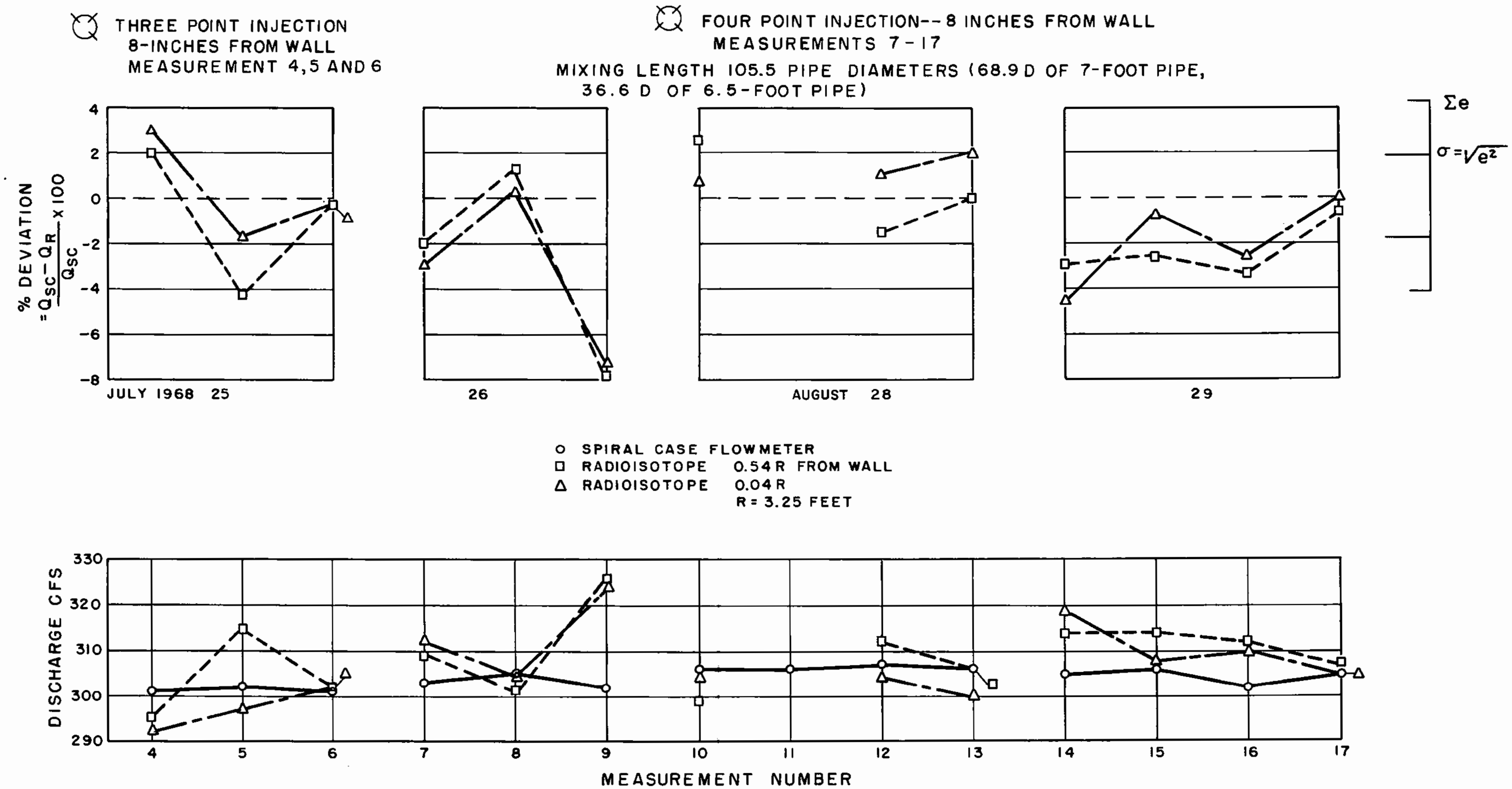
Table 5

DISCHARGES MEASURED BY
INTEGRATED SAMPLE METHOD

Measurement number	Spiral case flowmeter cfs	Sample Location 0.54R Discharge cfs	0.54R Deviation percent	0.04R Discharge cfs	0.04R Deviation percent
1–3	Measurements lost because of detector failure				
4	301	295	2	292	3
5	302	315	-4.3	297	+1.7
6	301	302	-0.3	302	-0.3
7	303	309	-2	312	-3
8	305	301	1.3	304	0.3
9	302	325	-7.9	325	-7.3
10	306	298	2.6	304	0.7
11	306	--	--	--	--
12	307	312	-1.6	304	1
13	306	306	0	300	+2
14	305	314	-3	319	-4.6
15	306	313	-2.6	308	-0.7
16	302	312	-3.3	310	-2.6
17	305	307	-0.6	305	0
		Mean	-1.5		-1.0

$$\text{Percent deviation} = \frac{Q_{sc} - Q_R}{Q_{sc}} \times 100$$

sc—spiral case flowmeter
R—radioisotope
Mixing length 105 pipe diameters



DISCHARGE MEASUREMENTS USING RADIOISOTOPE-INTEGRATED SAMPLE METHOD

TURBINE UNIT NO. 2

FLATIRON POWER AND PUMPING PLANT

FIGURE 15

Table 6

INTEGRATED SAMPLE METHOD

Estimated Errors in the Discharges Computed for
Spiral Case Flowmeter and Radioisotope Method

Number of measurements	Sampling point Mixing length 105.5 pipe diameters	Percent deviation $(Q_{sc}-Q_R)/Q_{sc} \times 100$	
13	0.54 of pipe radius from wall (R = 3.25 feet)	8 > 1.8% 2 > 4.2%	39% < 1.8% 85% < 4.2%
13	0.04R from pipe wall	6 > 1.8% 2 > 4.2%	54% < 1.8% 85% < 4.2%

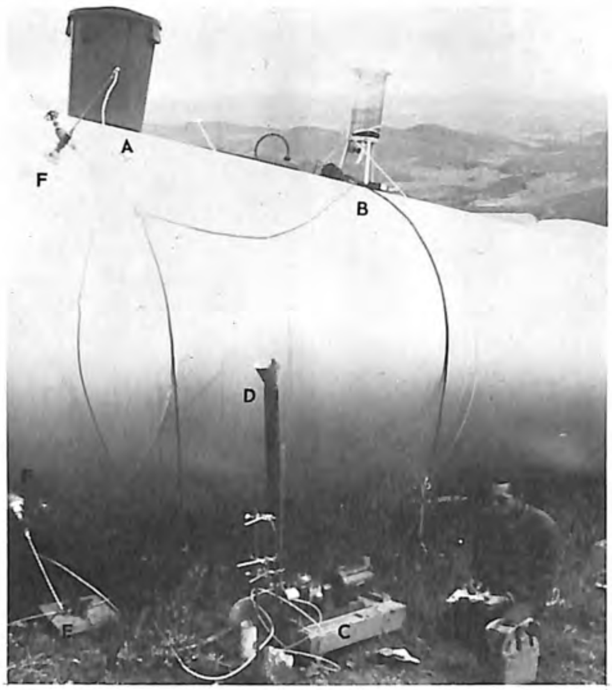
Standard deviation

(a) Flowmeter manometer reading = ±0.8%
(b) Radioisotope $\sqrt{\Sigma e^2}$ = ±1.0%
= ±1.8%

Total possible error

(a) Manometer (2σ) = ±1.6%
(b) Radioisotope Σe = ±2.6%
±4.2%

See Figure 15



Fluorescent Dye Injection System
(a) Water (b) Dye Mixing Tank (c) Diaphram Chemical Feed Pump (d) Buret for Injection Rate Measurement (e) Injection Manifold, and (f) Two of Four Injection Tubes. Photo P245-D-63696NA

Figure 16

regulated by valves to be the same for each instrument. The flow path length and size of tubing between the sample tubes and fluorometers were made equal to produce, as near as possible, the same mixing characteristics. Thus, with complete mixing in the penstock, the fluorometer output should be constant. Fluctuations in penstock concentration should be evident in the fluorometer output but slightly modified by the mixing length in the connecting tubing.

A four-point sampling system was located 36.5 diameters from the injection, Figure 18. The fluorometers were alternately connected to pairs of sampling tubes to measure the concentration. Movable sampling tubes were inserted through valves and stuffing boxes fitted to existing access pipes, Figure 19. The use of these sample tubes allowed extractions to be made at the wall and up to 8 inches into the flow. The radius of the pipe at the sample cross section was 3.5 feet, giving a sample distance of about 0.21 of the radius. Sampling tubes and flow rates were the same for each sampling point. The length of the connecting tube tended to partially damp concentration fluctuations in the sample stream. The measurement of fluorescence would thus indicate a more uniform concentration than actually occurred in the penstock.

Results of Diffusion Study

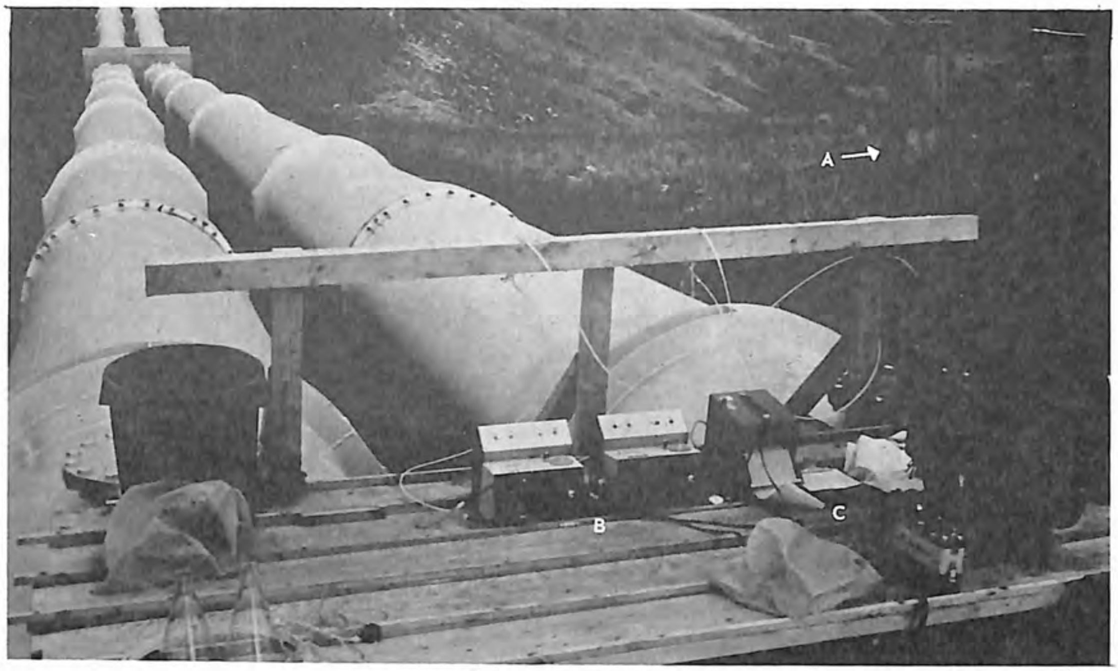
Variations in tracer concentration were 8 to 10 times larger at the 36.5-diameter mixing length than those occurring at 105 diameters, Figure 20. Changes in concentration of 40 ppb or larger occurring at 36.5 diameters were 50 percent or more of the mean concentration. Consideration of these fluctuations will be discussed further under the dilution method of measurement.

The period of the fluctuation, as well as the amplitude, was smaller for the 105-diameter mixing length. Both the 0.44R and 0.04R measuring locations showed nearly the same variation in amplitude of concentration, the mean being displaced by slightly different response characteristics of the fluorometers, Figure 21. The measured fluctuations in concentration amounted to 6 or 7 percent of the mean concentration. Variations in concentration at the two measuring points were essentially in phase. The phase difference on the chart was caused primarily by the displacement of the pen for the upper trace one small division ahead of the lower trace pen to provide for the deflection of both pens the full width of the chart.

Each of the small divisions on the chart represents about 6 seconds of time. Study of the traces from 11 dye injections showed that the variations in concentration from the mean occurred for times of about 6 to 30 seconds. The highest count rates at the sampling location for the pulse of radiotracer injected for the integrated-sample method occurred over a period of about 6 to 10 seconds. Thus, a variation in concentration, plus or minus, occurring in the same period as the peak count, could cause a part of the deviation for discharges in Table 5. A longer injection period (therefore a longer sampling period) could improve the accuracy of the integrated-sample method by reducing the effect of the concentration variations.

Dilution Method

Procedure—Results from the discharge measurements by the integrated-sample method and



Fluorescent Dye Sampling System at 105 Diameters—(a) Two Tube Sampling System Used for Radioisotope Discharge Measurements (b) Fluorometers, and (c) Two Channel Recording Voltmeter. Photo P245-D-63698NA

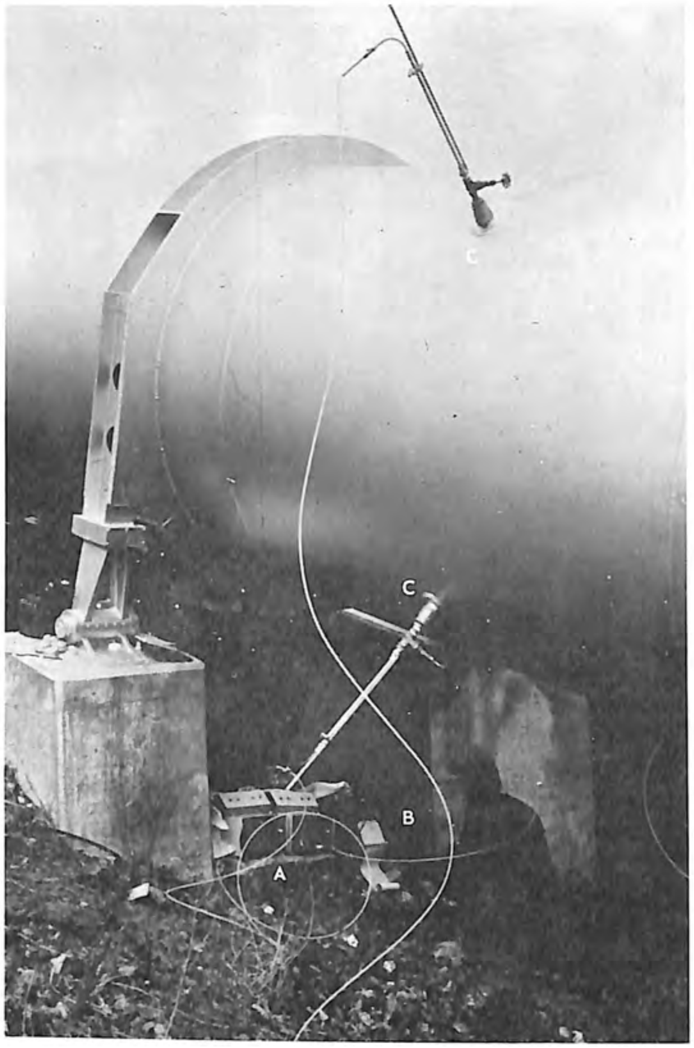
Figure 17

dye diffusion study indicated the dilution method could possibly produce the highest accuracy of flow measurement. A longer period of injection would permit a longer period of sampling and a better chance of averaging fluctuations in the concentration. The pressure injection system was modified to use the 3.7-liter cylinder as a radiotracer container, Figure 22. Mixing of the tracer and water in the cylinder was accomplished by (a) closing the valve between the pressure gage and cylinder, and (b) slowly pumping air through the gage glass to the bottom of the cylinder to escape out the opened valve at the top. Two to 3 minutes were sufficient to provide a uniform tracer-water mixture. Pressure from a nitrogen gas bottle was applied to the cylinder through a regulator. The cylinder was volumetrically calibrated and provided with a gage glass scale for determining the volume injected with respect to stopwatch time. Injections from the cylinder containing about 3 liters of solution were made at the rate of about 5 milliliters per second through the four-way manifold and four-tube system. The tubes projected 8 inches into the penstock flow.

The penstock pressure at the injection location was about 35 psi and the total injection pressure was 70 psi. The total change in cylinder pressure from beginning to end of the injection was about 0.65 psi or about 1 percent of the total injection pressure. The injection flow rate, corresponding to the segment used for the discharge computation, was estimated to have changed less than 0.75 percent.

For each injection of radiotracer for the dilution method, a discharge measurement was made by the total-count method at the powerplant. During the first four dilution measurements, monitoring of the cylinder showed small amounts of tracer were being retained in the "tee" at the cylinder outlet, Figure 22. The retention had no effect on the dilution measurement but did affect the accuracy of the total-count measurement. To provide for complete emptying of the cylinder the outlet piping was modified to eliminate the horizontal "tee," Figure 23.

Samples were taken from the penstock at 36.5 diameters for the dilution method and at 105



Fluorescent Dye Sampling System at 36.5 Diameters (a) Fluorometers (b) Recording Voltmeter, and (c) Sampling Tubes. Photo P245-D-63697NA

Figure 18

diameters and at 919 diameters for the dilution and total-count measurements. At the 36.5-diameter location, Figure 18, the four sample tubes were connected to a common pressure manifold. A single outflow sample bypassed from a higher flow through the manifold, was a blended sample from the four tubes. The sample collected in plastic containers after thorough mixing was transferred to the glass flasks for counting, Figure 12.

The two-point sampler was used at the 105-diameter location, Figure 14. The sample was extracted into plastic containers at the entrance to sample tanks installed for simultaneous total-count measurements, Figure 24. The samples collected in the plastic containers were transferred to glass flasks for the dilution-method counting, Figure 12. A digital-tape recording of the counted radiation was made in the mobile laboratory as the tracer-water sample passed through the sample tank. This record provided a radiation count for the dilution and total-count methods of measurement. Thus, for this series of measurements, liquid samples were taken for the dilution method at 36.5 and 105 diameters, tape records for dilution and for the total-count methods were taken at 105 diameters, and manual records for the total-count and dilution methods were taken at the powerplant.

Injections lasted from about 450 to slightly over 600 seconds for the 3 liters of tracer solution. Samples were extracted at the 36.5-diameter location for periods ranging from about 400 to 500 seconds depending on the injection time. Samples at 105 diameters were obtained for periods ranging from 280 to 300 seconds. Samples from both locations were obtained during the period of constant rate injection.

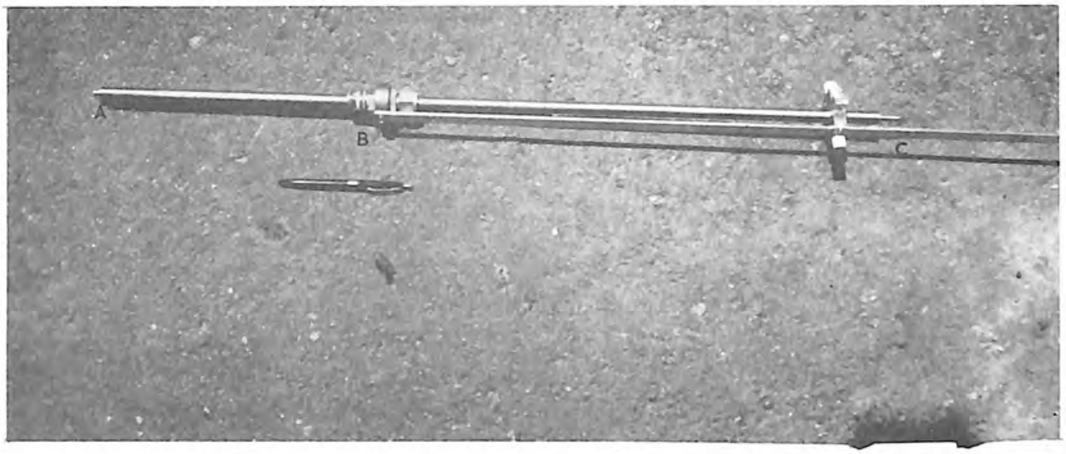
Discharges were computed from the basic equation

$$Q = q\,\frac{C_1}{C_2}$$

in the form

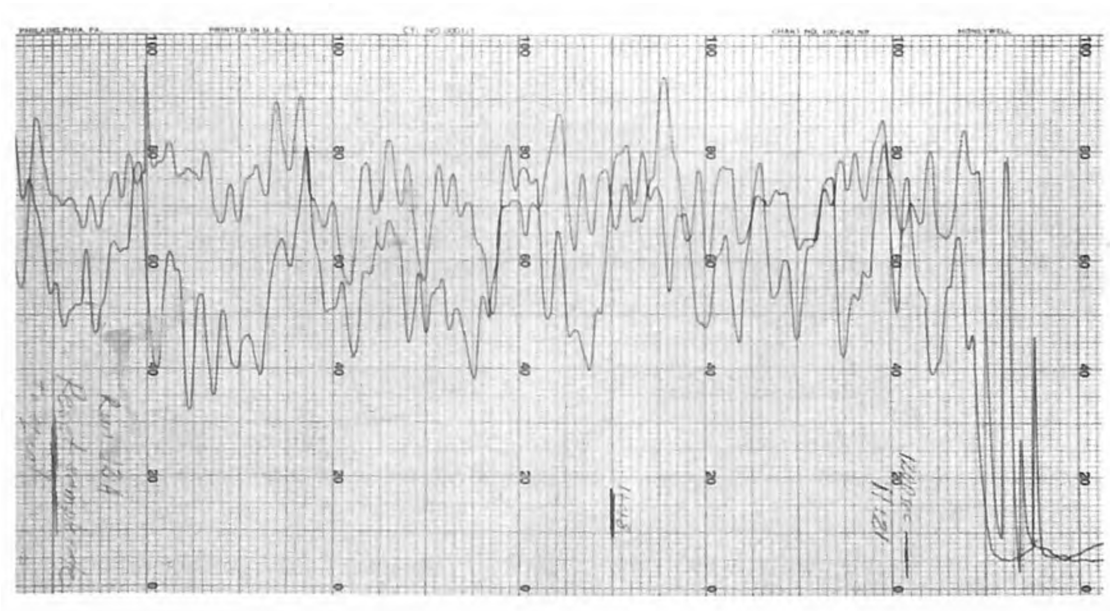
$$Q = q\,\frac{C_i f F}{R_n} \qquad C_2 = \frac{R_n}{fF} \quad \text{and}$$

$$F = \frac{R_k}{C_s}$$



Movable Injection or Sampling Tube—(a) 1/2-inch O.D. by 1/4-inch I.D. Tube, (b) Stuffing Box, (c) Positioning Bar. Photo P245-D-63699NA

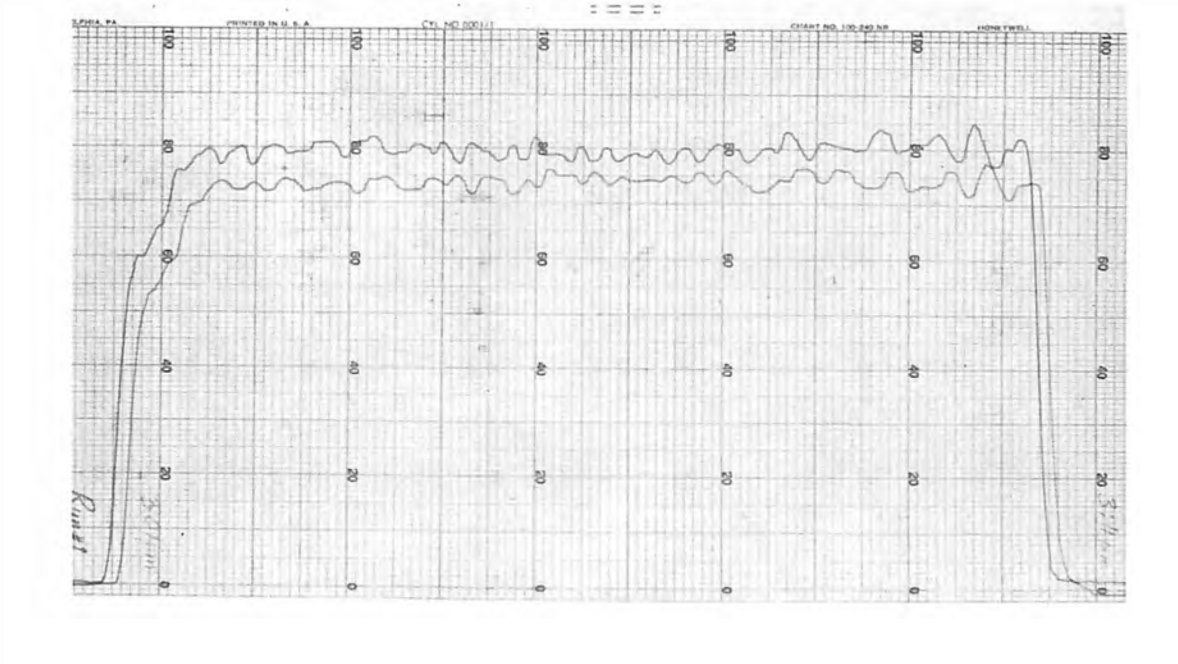
Figure 19



← CHART TRAVEL

Fluctuations in Dye Concentration 36.5 Pipe Diameters Downstream from Injection Point—Samples Taken 0.04 Foot from Pipewall (Chart Speed 1-inch per minute, Distance Between Numbered Scale Lines 2 inches). Photo P245-D-64977NA

Figure 20



← CHART TRAVEL

Fluctuations in Dye Concentration at 105.5 Pipe Diameters from Injection—Upper Trace 0.44 of the Pipe Radius from the Wall—Lower Trace 0.04 of Radius (Chart Speed 1-inch per minute, Distance Between Numbers Scale Lines, 2 inches). Photo P245-D-64976NA

Figure 21

where:

- q = injection rate (ml/sec)
- C_i = concentration of injection solution (μc/ml)
- f = decay correction factor
- F = calibration factor for flask and shield
- K = net counting of calibration
- C_s = concentration of calibration solution
- R_n = $(R_g - R_b)/f$ = net count rate corrected for decay
- R_g = gross count rate
- R_b = background count rate
- R_k = net count rate from calibration solution corrected for decay

Again with the exception of preparing the solution to be injected from the cylinder and the standard C_s, the radiation counting for the discharge measurements was performed at the field site.

Results of Measurements

Flask counting.—Deviations among discharges measured by the spiral case flowmeter and the dilution method at 36.5 diameters were only slightly larger than at 105 diameters, Table 7 and Figure 25. The blended sample obtained in the shorter mixing length showed a lower percentage deviation in discharge for the tubes extended 0.2 of the pipe radius into the flow. The deviations for the longer extension of the tubes were comparable to the deviations at 105 diameters of mixing length. Because only two or four measurements were made for each of the three tube extensions into the flow, no definite conclusions were made from the results. The results did indicate that the four-point injection

Tracer Injection System for Dilution Method–Tube at Bottom of Cylinder was Connected to the Four-outlet Manifold. Photo P245-D-63702NA

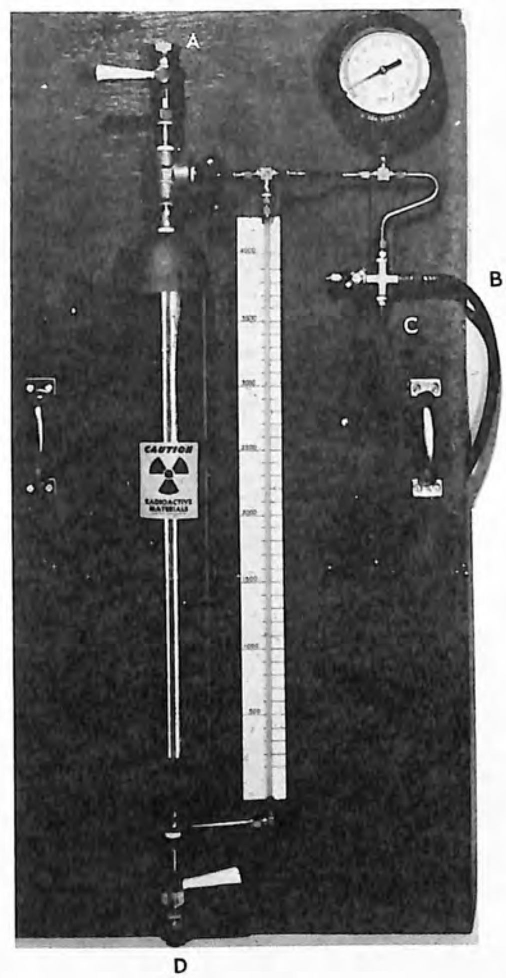
Figure 22

system combined with a multiple sampling system should be investigated in detail.

At 105 diameters, smaller deviations occurred but one value of 4 percent occurred for a sample taken near the pipe wall. Most of the values were larger than the desirable 1 percent or less deviation. Because of the longer period of sampling than used for the integration method, the deviations were possibly more dependent on radiation counting than on mixing. Variations were measured in the radiation count caused by differences in the counting flasks. Up to six flasks were used at the 105-diameter location to hold the samples. Counting, during the second series of measurements (5-8) was done in one flask after careful rinsing and transfer of the sample.

Temperature variations caused by the weather prevalent through the dilution measurement series. Experimental radiation counting was done in the laboratory with the scalers and detectors for a range of temperatures including those experienced in the field. These experiments showed a temperature effect on the counting efficiency amounting to a maximum of about 0.25 percent for a temperature difference of 20° F. These temperature corrections can be used in the future for refinement of the discharge computations.

Fifty-seven percent of the measurements made at 36.5 diameters deviated less than the estimated standard deviation, Table 8. Seventy-one percent



Injection System Modified at Outlet of Cylinder to Provide for Complete Evacuation of Tracer (a) Tracer Inlet (b) Low Pressure Air line (Tire Pump) for Mixing Tracer and Water (c) Injection Pressure (d) Outlet to Manifold and Penstock. Photo PX-D-64663

Figure 23

Sample Tank Containing Detector and Connected to Penstock Sampling System—Tube (a) To Drain, Tube (b) From Penstock, Tube (c) For Integrated and Diluted Samples. Photo P245-D-63704NA

Figure 24

were less than the estimated total error indicating that the shorter mixing length desirable in this study may be obtainable through multiple injections and samples. These procedures applied to the integrated-sample method could simplify the measurements and produce an acceptable level of accuracy.

At 105 diameters, the discharges computed from samples taken near the wall deviated less from the flowmeter than those away from the wall. Seventy-five percent were less than the standard deviation at the wall while 57 percent were less at the 0.54R location. The variations were too large and the accuracy was not acceptable. None of the discharges for the two positions exceeded the estimated total possible error.

Digital Tape Record.—Tape records were available for discharge computation from the sample tanks at 105 diameters and at the powerplant. The discharges computed from the records had deviations at 105 diameters ranging from -7.6 to -0.3 percent, Table 9 and Figure 26. The range was from +0.3 to -3.3 percent at the powerplant. According to these records the discharge computed from the radioisotope method was with one exception greater than that measured by the flowmeter.

The tank calibration may have been affecting these results. A sample was extracted from the flow at the entrance to the tank for radiation counting in the flask. The remaining flow passing through the tank was detected and counted to produce the tapes. The average counting rate (having lower statistical accuracy than the flask sample) was used to compute the discharge. The deviations for the counting flask averaged -0.3 at 0.54R to +0.6 at 0.04R. The average deviations were larger for the tape, a -1.8 at 0.54R and -3.4 at 0.04R. Discharges computed for the sample tank at the powerplant also averaged a greater amount by a -1.3 percent.

The dilution method using a counting flask appeared to give a slightly higher accuracy than the tape record but was more time consuming, Tables 9 and 10. The added mixing length to the powerplant sampling point did not give an average deviation below that for the flask counting. Better accuracy was shown for the longer mixing length to the powerplant by the manual record over that at 105 diameters. The improvement was not sufficient to determine that the count rate record can produce a statistical accuracy equal to the flask counting. An investigation of the possible refinements to both the flask and tank counting methods are necessary to establish the accuracy limitations.

Total Count Method

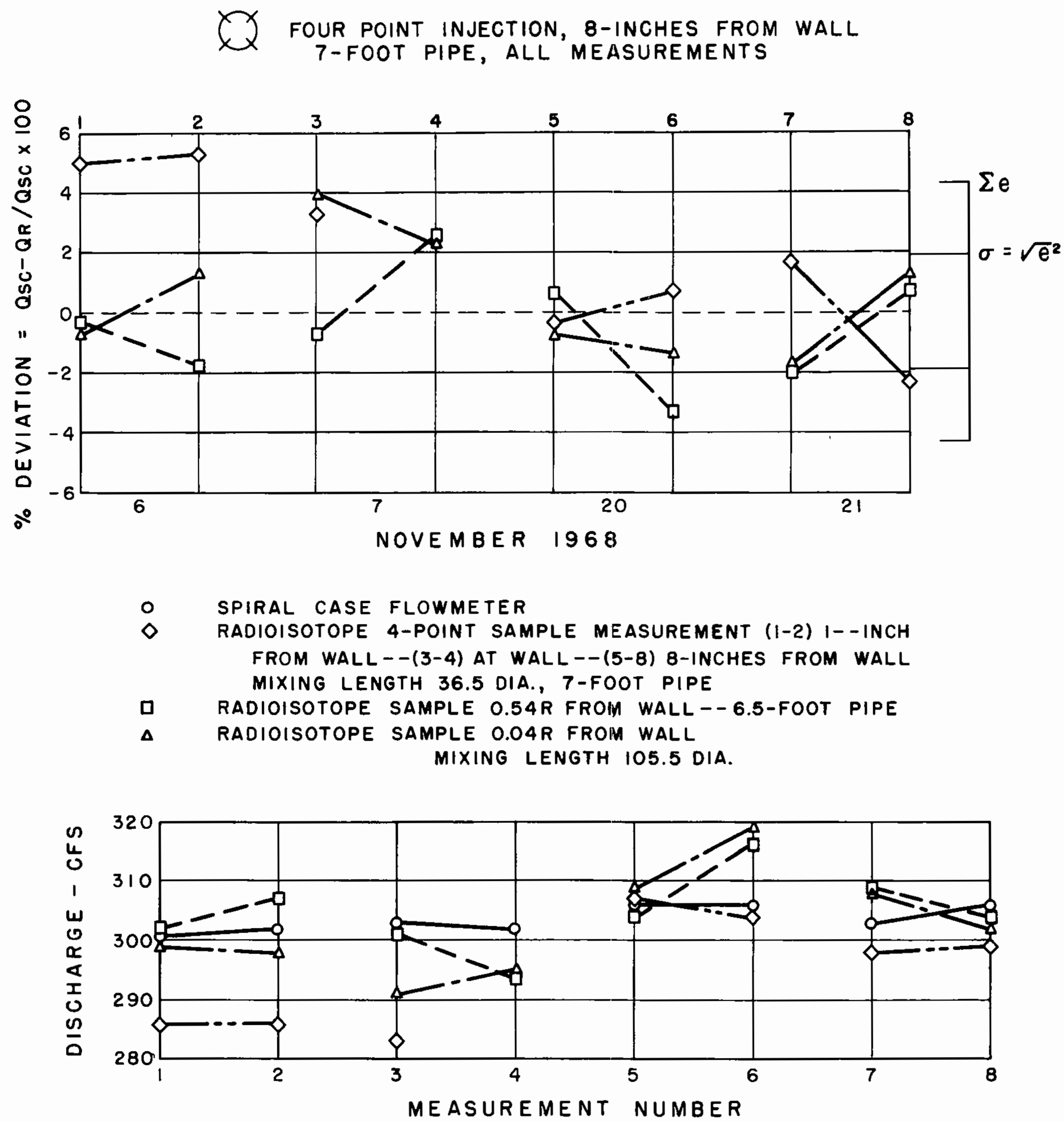
Procedure.—The total-count method was used at the powerplant for a monitor of the discharge for the maximum mixing length during the integrated sample measurements. Measurements were made using the calibrated sample tank and a manual recording of the scaler count. When the method was used in conjunction with the dilution measurements a digital tape record was printed in the mobile laboratory.

Table 7

DISCHARGES MEASURED BY DILUTION METHOD
(INTEGRATED SAMPLE COUNTED IN FLASK)

Measurement number	Flowmeter	Sampling location					
		36.5D		105.5D			
	Q_{sc}	Q_R					
	cfs	Discharge cfs	Deviation percent	Discharge cfs	Deviation percent	Discharge cfs	Deviation percent
		(0.04R from wall, 4 tubes)		(0.54R)		(0.04R)	
1	301	286	+5	302	-0.3	299	-0.7
2	302	286	+5.3	307	-1.7	298	+1.3
		(At plane of wall)					
3	303	283	+3.3	301	0.7	291	+4
4	302	--	--	294	+2.6	295	+2.3
		(0.2R from wall)					
5	306	307	-0.3	304	+0.7	308	-0.7
6	306	304	+0.7	316	-3.3	319	-1.3
7	303	298	+1.7	309	-2	308	-1.7
8	306	299	-2.3	304	+0.7	302	+1.3

Diameter at 36.5D = 7.0 feet R = 3.5 feet
Diameter at 105.5D = 6.5 feet R = 3.25 feet
Percent deviation $= \frac{Q_{sc} - Q_R}{Q_{sc}} \times 100$



DISCHARGE MEASUREMENTS USING RADIOISOTOPE - DILUTION METHOD

(INTEGRATED SAMPLE COUNTED IN FLASK)

TURBINE UNIT NO. 2

FLATIRON POWER AND PUMPING PLANT

FIGURE 25

Table 8

DILUTION METHOD

(Integrated Sample Counted in Flask)

Estimated Errors in the Discharges Computed for
Spiral Case Flowmeter and Radioisotope Method

Number of measurements	Mixing length	Percent deviation $(Q_{SC}-Q_R)/Q_{SC} \times 100$	
	36.5 diameters		
7	7-foot pipe—sample from four points on pipe circumference	3 > 1.9% 2 > 4.3%	57% < 1.9% 71% < 4.3%
	105.5 diameters		
8	0.54 of pipe radius from wall (R = 3.25 feet)	3 > 1.9% 0 > 4.3%	57% < 1.9% 100% < 4.3%
8	0.04R from pipe wall	2 > 1.9% 0 > 4.3%	75% < 1.9% 100% < 4.3%

Standard deviation

(a) Flowmeter manometer reading = ± 0.8%
(b) Radioisotope $\sigma = \sqrt{\Sigma e^2}$ = ± 1.1%
± 1.9%

Total possible error

(a) Manometer (2σ) = ± 1.6%
(b) Radioisotope Σe = ± 2.7%
± 4.3%

See Figure 25

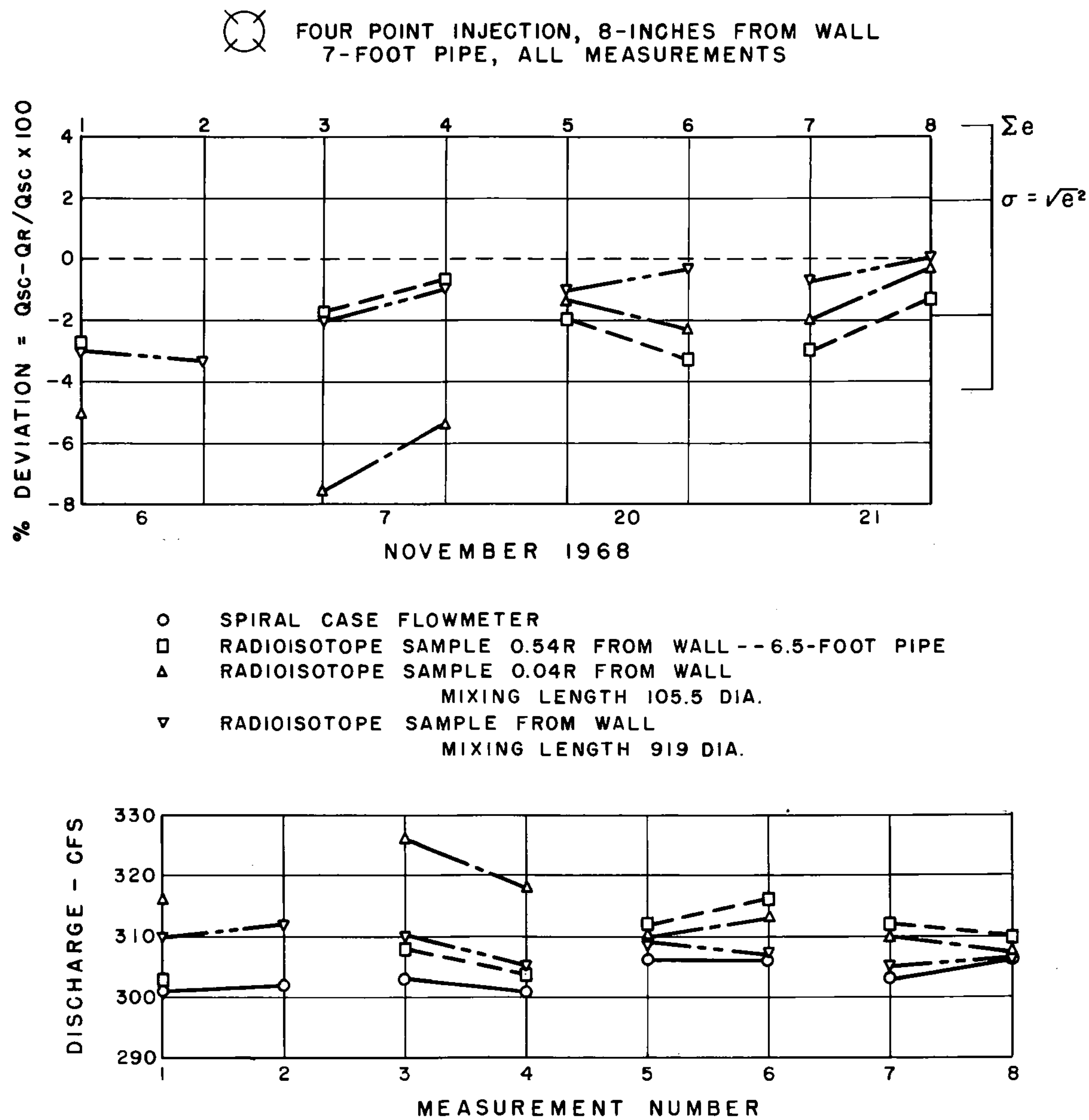
Table 9

DISCHARGES MEASURED BY DILUTION METHOD
(SCALER RECORD FROM SAMPLE TANK)

Measurement number	Flowmeter Q_{sc} cfs	Sample point 105.5D (0.54R) Discharge cfs Q_R	Deviation percent	Powerplant (0.04R) Discharge cfs	Deviation percent	(At wall) Discharge cfs	Deviation percent
1	301	303	-0.7	316	-5	310	-3
2	302	--	--	--	--	312	-3.3
3	303	308	-1.7	326	-7.6	310	-2
4	302	304	-0.7	318	-5.3	305	-1
5	306	312	-2	310	-1.3	309	-1
6	306	316	-3.3	313	-2.3	307	+0.3
7	303	312	-3	310	-2	305	-0.7
8	306	310	-1.3	307	-0.3	306	0

Diameter D = 6.5 feet R = 3.25 feet

Percent deviation = $\frac{Q_{sc} - Q_R}{Q_{sc}} \times 100$



DISCHARGE MEASUREMENTS USING RADIOISOTOPE - DILUTION METHOD

(SCALER RECORD FROM SAMPLE TANK)

TURBINE UNIT NO. 2

FLATIRON POWER AND PUMPING PLANT

FIGURE 26

Table 10

DILUTION METHOD

(Scaler Record from Sample Tank)

Estimated Errors in the Discharges Computed for
Spiral Case Flowmeter and Radioisotope Method

Number of measurements	Mixing length	Percent deviation $(Q_{SC}-Q_R)/Q_{SC} \times 100$	
	105.5 diameters		
7	0.54 of pipe radius from wall	$4 > 1.9\%$ $0 > 4.3\%$	$43\% < 1.9\%$ $100\% < 4.3\%$
7	0.04 of pipe radius	$4 > 1.9\%$ $3 > 4.3\%$	$43\% < 1.9\%$ $57\% < 4.3\%$
	919 diameters		
8	At pipe wall	$2 > 1.9\%$ $0 > 4.3\%$	$75\% < 1.9\%$ $100\% < 4.3\%$

Standard deviation

(a) Flowmeter manometer reading = ± 0.8%
(b) Radioisotope $\sqrt{\Sigma e^2}$ = ± 1.1%
± 1.9%

Total possible error

(a) Manometer (2σ) = ± 1.6%
(b) Radioisotope Σe = ± 2.7%
± 4.3%

See Figure 26

Discharges were computed from the total-count equation

$$Q = FA/N$$

where Q = Discharge (cfs)
F = Tank calibration factor
A = Quantity of injected tracer
N = Net radiation count from sample tank

Results of measurements.—Of the 17 total-count measurements made in conjunction with the integrated-sample method all but 1 was larger than the discharge indicated by the spiral case flowmeter, Table 11 and Figure 27. The average of the 17 was a -1.2 percent. Only 13 integrated-sample measurements could be compared to the total count. The -1.3 percent for the total count compared favorably in that the average deviation at 0.54R was -1.5 percent and at 0.04R was -1.0 percent. The maximum deviation for the total count method was -2.6 percent and for the integrated sample a -7.6 percent. The discharges measured by the integrated-sample method at 105 diameters showed a deviation range of -7.9 percent to +2.6 percent. The total count showed a range of -2.6 percent to +0.3 percent. A longer mixing distance for the total count produced better discharge measurements although the statistical error of radiation counting was higher than for the integrated sample.

The 919 diameters of mixing distance also produced smaller deviations by the total-count method than were obtained at 105 diameters, Table 12 and Figure 28. The average value at 105 diameters was -1.6 percent at 0.54R and -3.6 percent at 0.04R. An average of -0.4 percent was shown at 919 diameters. The measurements helped show the importance of mixing distance and the constancy of the measurements by the spiral case flowmeter. There appeared to be a tendency for the radioisotope method to indicate more discharge than the flowmeter. A more constant deviation between the flowmeter and radioisotope methods would suggest an under registration of the flow by the spiral case flowmeter.

Deviations between the spiral case flowmeter and radioisotope methods were all less than the estimated total possible error for the 919-diameter mixing length, Table 13. Only 54 percent were less at 105 diameters. The deviations were close to the expected values of the standard deviation. At 105 diameters the deviations exceeded both the standard and the estimated total error by a larger percentage than desirable. The pulse of tracer at the shorter mixing distance may have prevented a good sample and good counting accuracy in the tank.

CONCLUSIONS

Velocity method.—There appear to be two major causes of deviations between discharges computed from the velocity method and indicated by the flowmeter.

a. A single detector was used at each of sampling stations for recording the tracer passage. Because of the short mixing length between injector, an irregular change was recorded in the count rate.

b. The nonuniform increase and decrease in the count rate made computing the center of area of the tracer-water mixture difficult. Thus, establishing the flow time between detectors could not be done accurately which caused errors in computing the discharge.

Multiple detectors, three or more at each of the two cross sections would improve the averaging of the radiation count and computation of the center of area from the tracer-water mixture in the pipeline. An accurate measure of the volume of the pipeline between the detector array would be necessary for an accurate discharge measurement.

Integrated-sample method.—The accuracy of the integrated-sample method can probably be increased by improvements made in radiotracer handling and radiation counting procedures. The ultimate accuracy may be limited by the pulse type of injection used for the method. A sampling of the pulse of tracer-water mixture from a single point in the flow may not provide a satisfactory integration of the flow. The simplicity of the injection method and counting procedures suggests that additional study be made with a multiple sampling of the pulse to improve the discharge measuring accuracy.

Dilution method.—The use of a constant rate injection and sample counted in a flask produced the smallest average deviation between the radioisotope and spiral case measurements. The standard deviation of the dilution measurements was large, indicating an inadequate mixing or counting procedure.

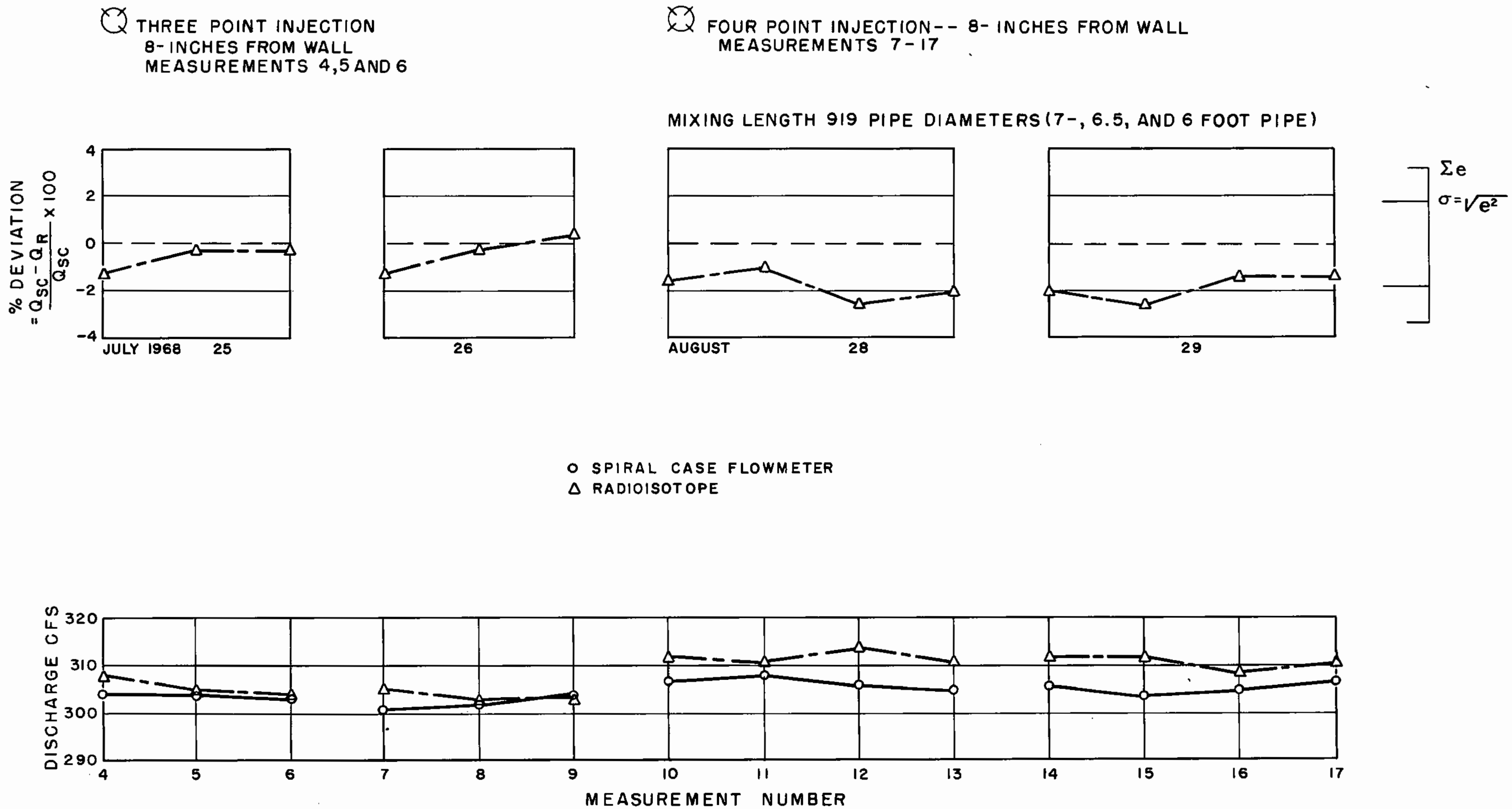
Table 11

DISCHARGES MEASURED BY TOTAL-COUNT METHOD
(IN CONJUNCTION WITH INTEGRATED SAMPLE)

Measurement number	Flowmeter Q_{sc} cfs	Sampling location Q_R 919D (At wall) Discharge cfs	Deviation percent
1	303	306	-1
2	302	304	-0.7
3	302	303	-0.3
4	304	308	-1.3
5	304	305	-0.3
6	303	304	-0.3
7	301	305	-1.3
8	302	303	-0.3
9	304	303	+0.3
10	307	312	-1.6
11	308	311	-1
12	306	314	-2.6
13	305	311	-2
14	306	312	-2
15	304	312	-2.6
16	305	309	-1.3
17	307	311	-1.3

Average = -1.2 percent

$$\text{Percent deviation} = \frac{Q_{sc} - Q_R}{Q_{sc}} \times 100$$



DISCHARGE MEASUREMENTS USING RADIOISOTOPE TOTAL-COUNT METHOD

(IN CONJUNCTION WITH INTEGRATED-SAMPLE)

TURBINE UNIT NO. 2

FLATIRON POWER AND PUMPING PLANT

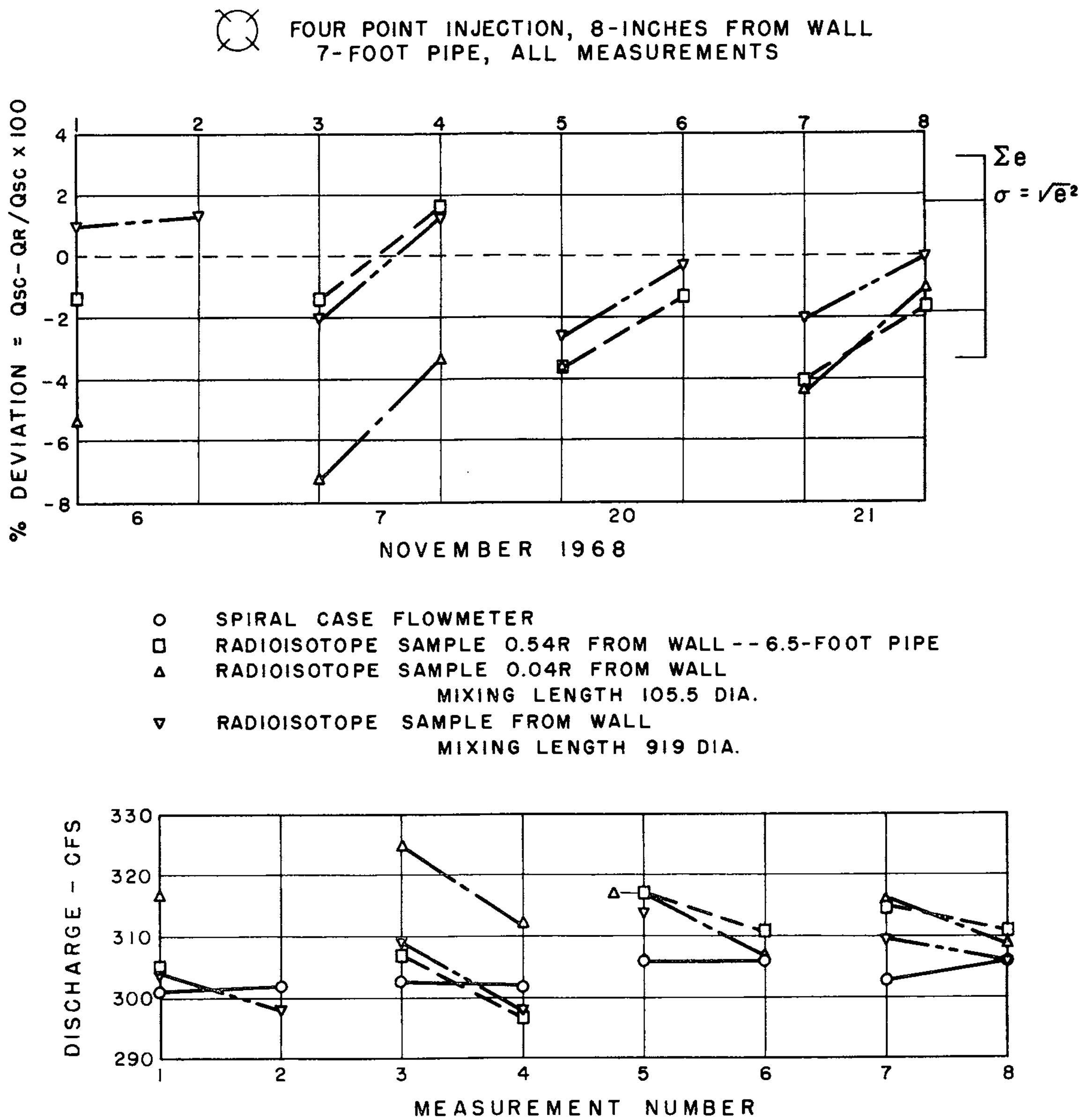
FIGURE 27

Table 12

DISCHARGES MEASURED BY TOTAL-COUNT METHOD
(IN CONJUNCTION WITH THE DILUTION METHOD)

Measurement number	Flowmeter Q_{sc} cfs	Sampling location Q_R: 105D (0.54R) Discharge cfs	105D (0.54R) Deviation percent	105D (0.04R) Discharge cfs	105D (0.04R) Deviation percent	919D (At wall) Discharge cfs	919D (At wall) Deviation percent
1	301	305	-1.3	317	-5.3	304	+1
2	302	--	--	--	--	298	+1.3
3	303	307	-1.3	325	-7.3	309	-2
4	302	297	+1.7	312	-3.3	298	+1.3
5	306	317	-3.6	317	-3.6	314	-2.6
6	306	311	-1.3	307	-0.3	--	--
7	303	315	-4	316	-4.3	310	-2
8	306	311	-1.6	309	-1	306	0

Percent deviation = $\frac{Q_{sc} - Q_R}{Q_{sc}} \times 100$



DISCHARGE MEASUREMENTS USING RADIOISOTOPE - TOTAL COUNT METHOD

(SAMPLE TANK IN CONJUNCTION WITH DILUTION METHOD)

TURBINE UNIT NO. 2

FLATIRON POWER AND PUMPING PLANT

FIGURE 28

Table 13

TOTAL COUNT METHOD

Estimated Errors in the Discharges Computed for
Spiral Case Flowmeter and Radioisotope Methods

Discharge Measurements

Number of measurements	Mixing length diameters	Percent deviation $(Q_{sc}-Q_R)/Q_{sc} \times 100$	
14 (In conjunction with integrated sample method)	919	4 > 1.8%	71% < 1.8%
		0 > 3.3%	100% < 3.3%
13 (In conjunction with dilution method)	105.5	7 > 1.8%	46% < 1.8%
		6 > 3.3%	54% < 3.3%
8 (In conjunction with dilution method)	919	3 > 1.8%	63% < 1.8%
		0 > 3.3%	100% < 3.3%

Standard deviation

(a) Flowmeter manometer reading = ± 0.8%
(b) Radioisotope $\sqrt{\Sigma e^2}$ = ± 1.0%
± 1.8%

Total possible error

(a) Manometer (2σ) = ± 1.6%
(b) Radioisotope Σe = ± 1.7%
± 3.3%

See Figures 15, 27, and 28.

The counting accuracy for the flask sample was higher than for the scaler record but the standard deviations of the measurements were about the same. A detector with greater sensitivity used in a sample tank probably could produce a higher counting accuracy in less time than shown in the dilution measurement series. Refinement of the procedures could eliminate the need for collecting a sample to be counted in a flask.

Care should be exercised in selecting the counting flasks. Differing glass quality caused variation in the counting rate for the flasks used in preliminary stages of the dilution measurements.

The dilution method of measurement using an integrated sample of the tracer-water mixture counted in a flask, showed the capability of measuring discharge more accurately than the velocity, integrated sample, or total-count methods. The time needed for the dilution measurement may be a limitation.

Total-count.—Total-count measurements made in conjunction with the integrated sample and dilution methods produced the same order of accuracy for mixing lengths of 105 and 919 diameters. The deviations from samples at the powerplant indicated the longer mixing length improved the accuracy. The total-count method using a tank supplied by a multiple sampling of the flow might be developed to a satisfactory level of accuracy for relatively short (30-35 diameters) of mixing length.

General.—Mixing lengths of 100 pipe diameters or more appear to produce the higher accuracies of measurements. Nearly all of the measurements of Phase IV were made from injections near the wall of the pipe and from four points in the cross section. With the exception of the sample taken at 36.5 diameters all sampling of the flow was through single orifices. At the 36.5-diameter distance, four holes 90^{o} apart in the same cross section were connected to withdraw a single sample. The results of the discharge measurement are shown on Tables 1 and 2. Discharges computed from measurements at both the 36.5 and 105.5 diameters show about the same deviation from the spiral case flowmeter. This agreement would indicate that for the multiple injection a shorter mixing length can be used if multiple samples are blended into one sample or are averaged from multiple samples.

For all of the radioisotope methods there are measurements that exceed the error that could be estimated for procedures and equipment used in these measurements. The errors in the procedures of dilution calibration, decay factors, etc., are probably approaching a minimum value. A critical review may reveal ways of eliminating or improving some of the steps being used in preparation of calibration solutions and the radioisotope fraction being injected for the measurement. Such improvement could reduce the total error to be expected in a measurement.

Improvements can be made in the counting of the radioisotope-water mixture extracted from the pipe for the discharge measurement. This improvement could be accomplished by counting the mixture for longer periods to increase the statistical accuracy, better shielding of the detectors, and increasing the ratio of the sample to background count rate. A temperature effect on the detectors was noted during the dilution measurements. Subsequent studies on the counting system gave the order of magnitude of the effect. The temperature effect and other counting irregularities will be analyzed in an effort to find reasons for measurements deviating beyond the expected error.

ADDENDUM

USE OF TRITIATED WATER AS A TRACER

USE OF TRITIATED WATER AS A TRACER

Discussion.—A part of the research program on discharge measurements includes evaluating radioactive tracers. Initial investigations were reported in TID 23737 covering tracers having a radiological half-life of 1 to 9 days. In Phase IV a limited laboratory study of tritium was made to determine the feasibility of using the tracer for discharge measurements.

Tritium has wide acceptance as a good water tracer. Because of the soft beta radiation and reduced radiation hazards the tracer could be of advantage in making discharge measurements. Problems of handling a tracer in the field would be reduced and a procedure possibly could be developed to allow project personnel with minimum experience in isotope technology to perform discharge measurements.

A review was made of the advantages and disadvantages. The use of tritium would eliminate the need for massive shielding in transport and at the field site. The long half-life would permit field measurements over an extended period of time without significant losses by radioactive decay. A stock of tritium stored at a central location could supply several places for field discharge measurements. The amount of equipment would be substantially reduced because no precision isotope detecting instrumentation would be needed at the field site.

One of the primary objectives of this program is to develop rapid and precise techniques for using radioisotopes in high-head discharge measurements. Using tritium, one of the important disadvantages is that the samples must be returned to a counting laboratory for analysis. Thus, the use of tritium would be limited to measurements not requiring immediate results in the field.

Liquid scintillation counting, accepted as the most practical technique for widespread utilization of the method, would have an error of about ±1 percent. Laboratory tests in the Bureau have confirmed this error. The error is primarily due to variations in the efficiency of the liquid scintillation media. The accuracy can be improved by preparation and counting of multiple samples. Since the presence of tritium cannot be monitored in the field, collection of a sample from a pipeline would depend entirely upon estimating the velocity of flow and the time of arrival and departure of the tracer at the point of sampling. The possibility of missing part of the tracer presents an undesirable uncertainty when making precision discharge measurements.

Conclusions.—Tritium is a good tracer for water measurement and would greatly simplify the field procedures for flow measurement, but would be of marginal benefit over the use of a good gamma emitting tracer such as Bromine-82. The primary disadvantage is the limited precision for tritium measurement. A preliminary result of the discharge measurement is often quite important before leaving the field site. Using tritium, the discharges could not be conveniently computed until a later time.

For measurements not requiring immediate results and with improved radiation detecting and counting techniques, tritium may offer a satisfactory tracer for discharge measurements.

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