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DISCHARGE MEASUREMENTS USING RADIOISOTOPES AT FLATIRON AND POLE HILL POWERPLANTS

August 1970

Bureau of Reclamation
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RADIOISOTOPE AND RADIATION
APPLICATIONS (TID-4500)

DISCHARGE MEASUREMENTS USING RADIOISOTOPES AT FLATIRON AND POLE HILL POWERPLANTS

by
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August 1970

Chemical Engineering Branch
Division of Research
Office of Chief Engineer
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
Walter J. Hickel, Secretary
Ellis L. Armstrong, Commissioner

ABSTRACT

Radioisotope techniques and equipment were developed to improve methods for measuring flow rate in high-head turbines and pumps. Phase V, the last of a series of field measurements, was performed at Flatiron and Pole Hill Powerplants in Colorado. Studies of 4-point injection and sampling over a mixing length of 36.5 pipe diameters of 7-ft pipe (2.13 m) showed that radiation sampling and counting techniques were satisfactory. The mixing length appeared to be short for satisfactory mixing and accurate discharge measurement. A demonstration of the techniques at Pole Hill Powerplant produced satisfactory measurements for a mixing length of 255 diameters of 8-ft (2.44 m) pipe. Discharge of 400 cfs (11.2 cms) computed by the dilution, integrated sample, and total count methods varied up to about 2%, indicating that further refinement of sampling and counting techniques will not reduce significantly the inaccuracy below the estimated probable 2 Sigma error of 1.5%.

KEY WORDS AND DOCUMENT ANALYSIS

DESCRIPTORS--/ hydraulics/ physics/ *water measurement/ *radioisotopes/ penstocks/ field tests/ *tracers/ turbines/ water sampling/ *discharge measurement/ injectors/ pipelines/ radioactivity techniques/ Colorado/ dilution

IDENTIFIERS--/ Flatiron Powerplant, Colo/ Pole Hill Powerplant, Colo/ Atomic Energy Commission/ *mixing length/ radioactive tracers

COSATI Field/Group

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The investigation was materially assisted by the work of G. A. Teter, U. J. Palde of the Research Division, and the personnel operating the Flatiron and Pole Hill Powerplants under the supervision of Project Manager J. E. Stokes and Superintendent L. Willits.

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INTRODUCTION

The Atomic Energy Commission (AEC) and the Bureau of Reclamation (USBR) are cooperating in a research program for measuring discharge through high-head turbines and pumps using radioisotopes. The purpose of the program is to make discharge measurements accurately, quickly, and with a minimum of personnel and equipment. It was hoped that the program would develop the method to a precision that would allow discharge measurements to be made accurate within plus or minus 3/4 of 1 percent.

The program was divided into five phases and the results of the fifth are published in this report. The results of Phases I and II were reported to the AEC by the Bureau in AEC Report No. TID-23737, "Discharge Measurements Using Radioisotopes in High-Head Turbines and Pumps," September 1966. Phase III results were furnished in AEC Report No. TID-25177, "Discharge Measurements Using Radioisotopes in High-Head Turbines and Pumps at Flatiron Power and Pumping Plant," December 1968. Results from Phase IV of the study were furnished by the Bureau and published by the AEC in TID-25185, "Discharge Measurements Using the Radioisotope Velocity, Integrated Sample, Dilution, and Total Count Methods at Flatiron Power and Pumping Plant," July 1969.

In general, during the first four phases with steady flow in the penstock, the radioisotope method indicated discharges that varied over a larger range than desired. Exact causes for the variations could not be readily found but were attributed to anomolies in the techniques of sampling and/or counting the tracer-water mixture. Improvements were made in the counting and sampling techniques. Measurements in Phase V were performed to disclose whether the measurement accuracy and repeatability had been improved.

Results of the Phase IV study showed mixing lengths of 100 diameters or more produced measurements that indicated the accuracy goal could be achieved. Included in the Phase IV series were measurements having a multiple injection and sampling system for a pipe length of 36.5 diameters of 7-foot (2.13-meter) pipe, Table 1. Discharges computed from measurements at both the 36.5 and 105.5 diameters showed about the same deviation from the comparative measuring device. Because of the relatively close agreement, additional study was warranted for the 36.5-diameter length. These studies were made to determine the order of accuracy of measurement for multiple injections and multiple samples. In addition, discharge measurements using radioisotopes were made for the maximum obtainable mixing length in the penstock of Flatiron Powerplant.

The measurement techniques were later applied in a demonstration at the Pole Hill Powerplant.

STUDIES AT FLATIRON POWERPLANT

Measurement Facilities

Detailed descriptions of the powerplant have been furnished in previous reports (TID 25177 and 25185). Therefore, Figures 1 and 2 included here show only the physical conditions of the test site and locations of injection and sampling equipment.

Radioisotope injections were made with a system pressured by nitrogen gas, Figure 3. A 3.7-liter cylinder (a) was used as a radioisotope container. Mixing of the tracer and water in the cylinder was done by (1) closing valve (b) between the pressure gage and cylinder and (2) slowly pumping air (c) through the gage glass (d) to the bottom of the cylinder and allowing the air to escape out of the opened valve (e) at the top. The radiotracer was injected into the penstock through an outlet tube (f) and four-way manifold by applying the gas pressure through tube (g). Four, 1/4-inch (0.64-cm) diameter, stainless steel tubes (h) restricted by 1/64-inch (0.4-mm) orifices were used to pass the radiotracer from the injection system to the water in the penstock. The 1/4-inch (0.64-cm) tubes projected into the flow 8 inches (20.3 cm), about 0.2 of the pipe radius.

The injection rate for the radioisotope was controlled by the regulated nitrogen pressure and monitored on the gage glass by using binoculars. Injections from the cylinder containing about 3 liters of solution were made at a rate of about 8 milliliters per second. The penstock pressure at the injection location was about 35 psi (2.4 kg/sq cm) and the total injection pressure was 100 psi (7.0 kg/sq cm). The total change in cylinder pressure from beginning to end of the injection was about 0.65 psi (0.05 kg/sq cm) or about 0.7 percent of the total injection pressure. The injection flow rate changed less than 0.45 percent for the 0.65 psi pressure change.

Samples of the tracer-water mixture were taken from the penstock at 36.5 diameters and at the entrance to

Table 1

DISCHARGES MEASURED BY DILUTION METHOD
(INTEGRATED SAMPLE COUNTED IN FLASK)
(1968)

Measurement number	Flowmeter Q_{sc} cfs	36.5D Discharge cfs	36.5D Deviation percent	105.5D Discharge cfs	105.5D Deviation percent	105.5D Discharge cfs	105.5D 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

Sampling location: 36.5D, 105.5D (Q_R)

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

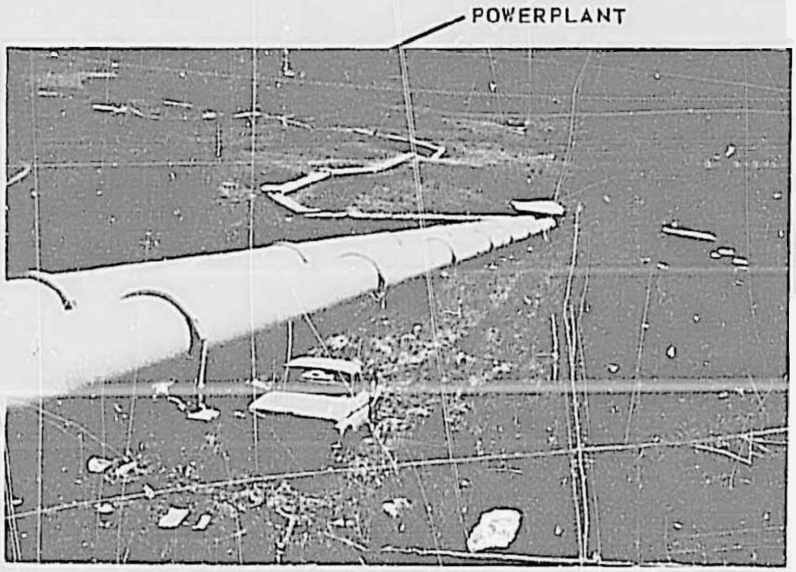


Figure 1. Flatiron Powerplant penstocks--Radioisotope injection equipment in foreground, sampling and counting equipment near mobile nuclear laboratory in background. Photo P245-D-65583

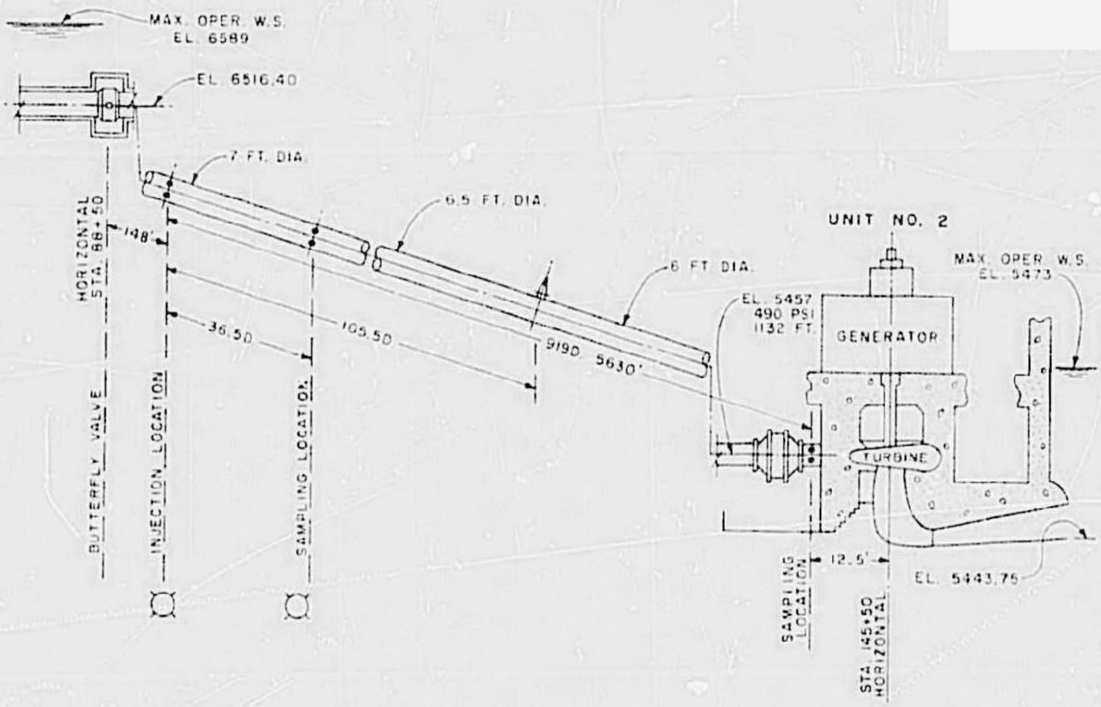


Figure 2. Flatiron Powerplant and penstock section—Injection and sampling locations.

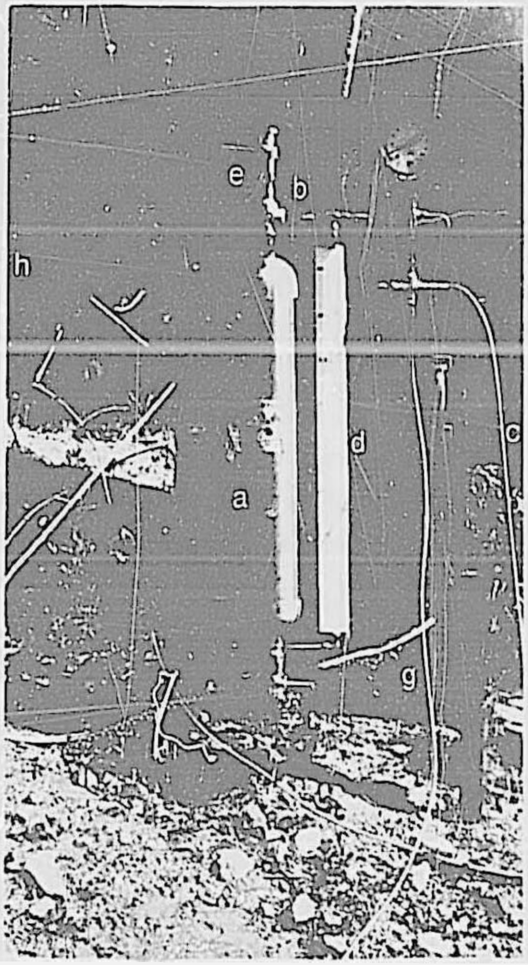


Figure 3. Injection system—(a) cylinder; (b) valve; (c) air hose from tire pump; (d) gage glass. (e) filling and vent valve; (f) outlet tube to four-way manifold; (g) nitrogen pressure line; and (h) stuffing box and injection tube. Photo P245-D-65584

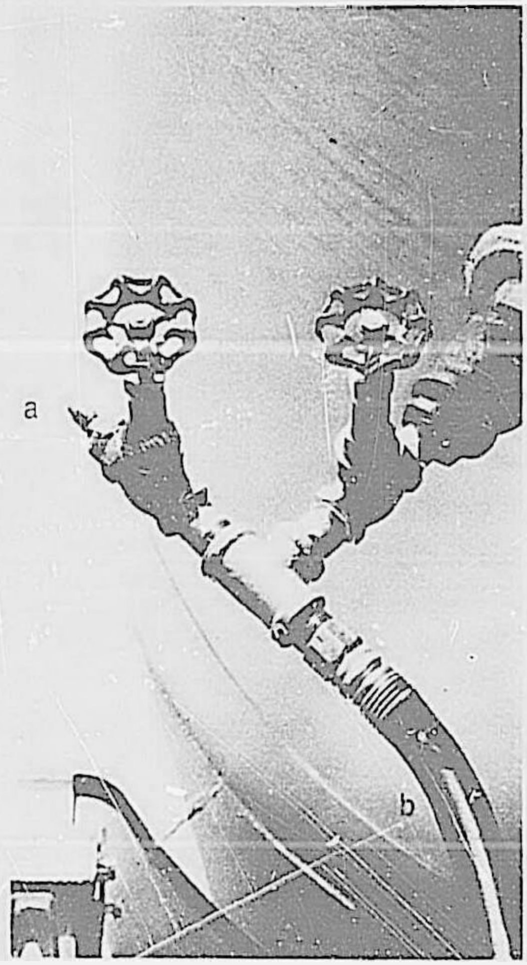


Figure 4. Penstock sampling connection—(a) tube for discrete sample and (b) hose to manifold. Photo P245-D-65580

the turbine at 919 diameters, Figure 2. At 36.5 diameters four 2-inch (5.1-cm) diameter access pipes in the wall of the penstock were connected to a common manifold for a sample tank measurement. Each of these connections also contained tubing for extracting discrete samples from each of the four penstock outlets, Figures 4 and 5. Individual sample tubes were connected to a multiple container sampler, Figure 6. A large sample volume of 2 to 3 gallons (9 to 14 liters) was collected in 120 to 250 seconds by using this device. After thorough mixing in the plastic containers the samples were trasnferred to glass flasks, Figure 7. These 2.0-liter flasks of tracer-water and background samples were taken to the mobile nuclear laboratory for counting, Figures 8 and 9.

The total count sample tank was connected to the manifold by a 50-foot-long 3/4-inch (1.9-cm) diameter hose, Figure 8. A discharge of about 15 gallons per minute (0.7 liters per second) flowed through the tank. A tracered sample was taken from the 3/4-inch (1.9 cm) diameter hose at the entrance to the tank through a 50-foot-long piece of 3/8-inch (9.5-mm) diameter plastic tube. This sample was collected in a plastic container coincident with the discrete samples, Figure 6. After thorough mixing, a part of the sample was placed in a flask for counting.

The samples in the glass flasks were counted in a shielded chamber, Figure 9. A 2- by 3-inch (5- by 7.6-cm) NaI(Tl) scintillation crystal optically bonded to a photomultiplier was centered at the bottom of the flask and shield. Thus the samples were counted in the mobile laboratory at the measurement site.

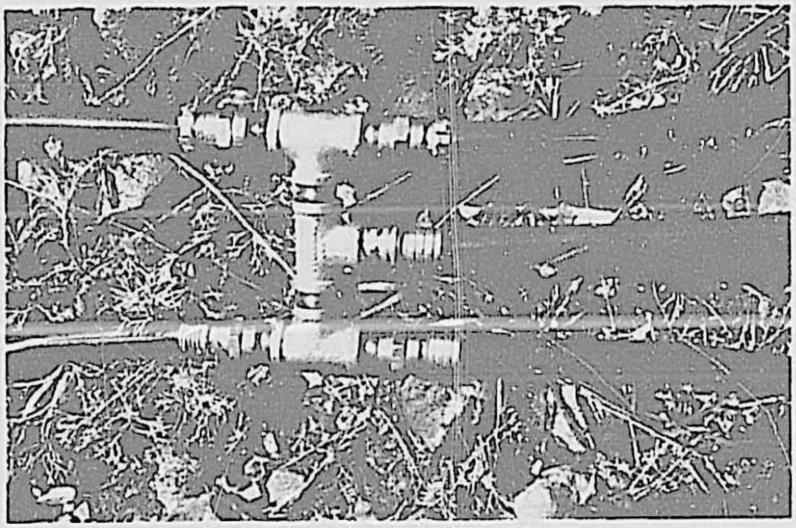


Figure 5. Sampling manifold of 3/4-inch pipe and hose—(a) hose to sample tank. Photo P245-D-65586

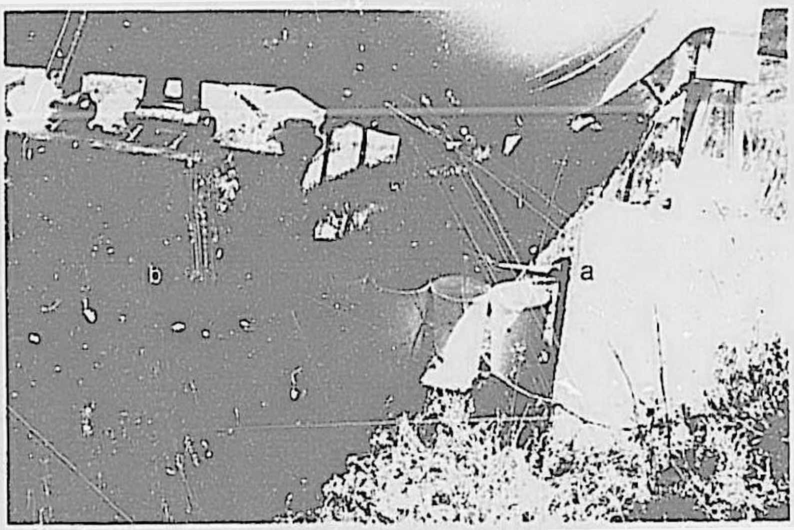


Figure 6. Multiple sampler at 36.5 pipe diameter—(a) discrete samples and (b) container for blended sample from entrance to total count sample tank. Photo 245-D-65592

Figure 7. Flasks containing samples—(a) from 36.5 pipe diameters and (b) from powerplant. Photo P245-D-65582

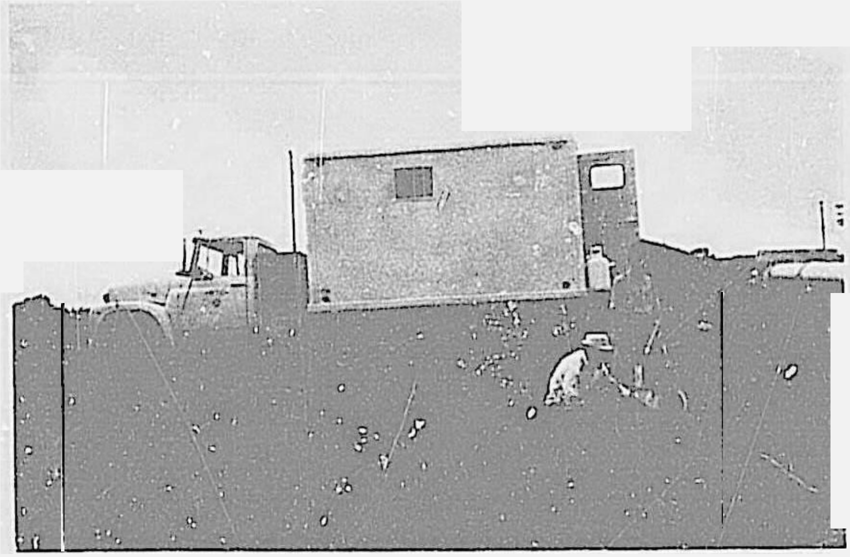


Figure 8. Mobile nuclear laboratory and sample tank. Photo P245-D-65581

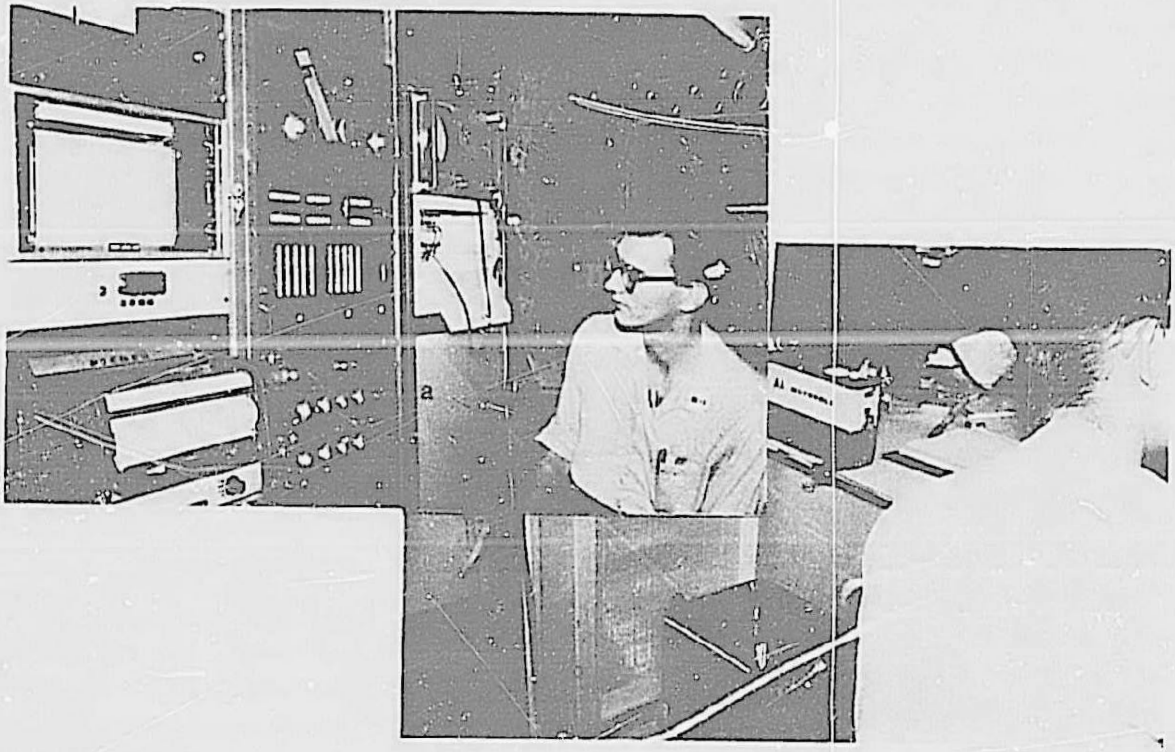


Figure 9. Radiation counting--(a) scalers and recorders and (b) counting shield. Top Photo P245-D-65590, bottom Photo P245-D-65589

One sample was taken at the entrance to the turbine for each of the radiotracer injections. This sample was taken from four 1/4-inch (0.64-cm) holes through the pipe wall at 45° on the circumference. Outside the pipe a 3/4-inch (1.9-cm) pipeline manifold connected to a 1/4-inch (0.64-cm) plastic tube was used to collect the sample in a large plastic container. After thorough mixing the sample was transferred to a bottle and then a flask for counting.

Radioisotope Discharge Computation

Discharges were computed from the basic dilution equation:

$$Q = q\frac{C_1}{C_2} \qquad \text{Eq 1a}$$

in the form

$$Q = q\frac{C_1 fF}{R_n} \qquad \text{Eq 1b}$$

$$C_2 = \frac{R_n}{fF} \quad \text{and}$$

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

where:

q = injection rate (ml/sec)
C_1 = concentration of injection solution (μc/ml)
f = decay correction factor*
F = calibration factor for sample flask and shield
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

*The decay correction factor is a variable with time, therefore its value is not constant.

All radiation counting was performed using the equipment in the mobile laboratory, Figure 9.

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 system. The discharge indicated by the flowmeter was compared to the discharges measured by the radioisotope method to determine the repeatability of the radioisotope measurements.

A calibration of the flowmeter was performed in 1954 by the salt velocity method. Before conducting the radioisotope measurement 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 (17.8 cm) of mercury for a turbine discharge of 500 cfs (14.2 cu m/sec). A mercury U-tube manometer and differential pressure transducer were connected across the pressure orifices, Figure 10. To minimize fluctuations in the differential pressure, 1/16-inch (1.6-mm) inside diameter by 94-inch (239-cm) long damping coils were placed in the piping ahead of the transducer and manometer. An amplifier, digital counter, and tape printer were used to record the differential in inches of mercury. Integration of the differential was made for 10-second intervals and then printed on tape. Segments of these tape readings corresponding to the time of constant rate of tracer injection were used to determine the rate of flow in the pipe. Average manometer differentials were taken from the tape to determine the discharge from the flowmeter calibration curve.

Figure 10. Spiral case flowmeter instruments—(a) mercury manometer; (b) pressure transducer; (c) damping coils; and (d) amplifier, digital counter, and printer. Photo 245-D-65595

Results of Discharge Measurements

Discharges computed by the radioisotope dilution method from discrete samples taken at 36.5 diameters did not show satisfactory mixing of the tracer and flowing water, Table 2 (Columns A, B, C, and D).

Tables 3A, B, and C and 4A, B, and C (Appendix) include the radiological counting data used in computing the discharges of Table 2. Included in Tables 3 and 4 are the statistical errors of counting the samples taken from the penstock.

Table 2

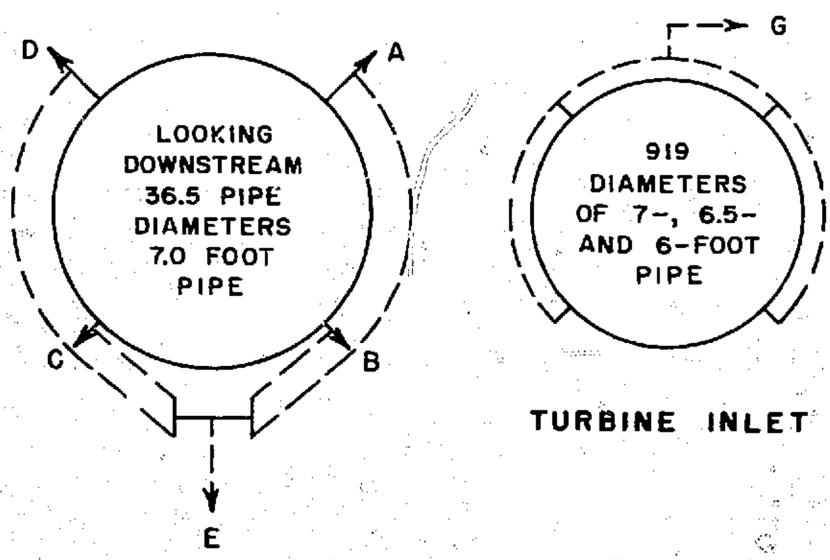
DISCHARGES MEASURED BY DILUTION METHOD
(1969)

Measurement number	Sample A	B	C	D	E	F*	G	Spiral case flowmeter
	(cubic feet per second)							
D–9	303	213	280	837	305	311	325	306
D–10	285	205	279	896	300	302	318 ***	305
D–11	348	273	284	298	302	303	375	306
D–12	293	272	306	327	298	300	368	306
D–13	395	264	277	274	306	296	312	303
D–14	397	253	275	272	305	295	312	303
D–15	296	263	313	314	291	296	310	303
D–16	304	256	318	321	296	281	313	301

(cubic feet per second x 0.0283168 = cubic meters per second)

*F = A + B + C + D in equal volumes
***Excessive sampling time

Counted in flask



Samples taken from the pipe at A, upper right quadrant, showed larger variations than at the other sampling points, Table 2 and Figure 11. Samples from B, lower right, resulted in consistently lower discharges than the other taps. With the exception of Measurements D–9* and D–10 discharge measurements based on taps C and D agreed favorably, Figure 11.

The large values of discharge computed for Measurements 9 and 10 at position D were believed to be caused by a partial plugging of the small injection orifice. The orifices were cleaned the following day. Results thereafter did not show as large a variation from the arithmetic mean.

The smallest deviation between the computed discharge and that indicated by the spiral case flowmeter was Sample E. With Sample E the isotope could have undergone mixing in 50 feet (15.2 m) of hose and about 50 feet of plastic tubing. When compared with the spiral case flowmeter in the equation:

$$\% \text{ deviation} = \frac{Qsc - QR}{Qsc} \times 100 \qquad \text{Eq 2}$$

The deviation ranged from a +0.7 percent to a +5.6 percent.

The radioisotope method showed discharges less than the flowmeter. This could imply that with injection near the wall the tracer had not diffused completely across the sampling section. These results indicate once again either inadequate mixing or possibly inadequate sampling techniques. Large volume samples and careful preparation of the counting flasks tended to minimize errors due to sampling.

Blending of equal parts of the four discrete samples (F) into a composite did not provide satisfactory results with respect to the program goal. The variations in the computed discharges were slightly higher than for the samples mixed by flow in the hose and plastic tubing. The deviation ranged from +7.6 percent to a –0.7 percent, Sample F, Table 2.

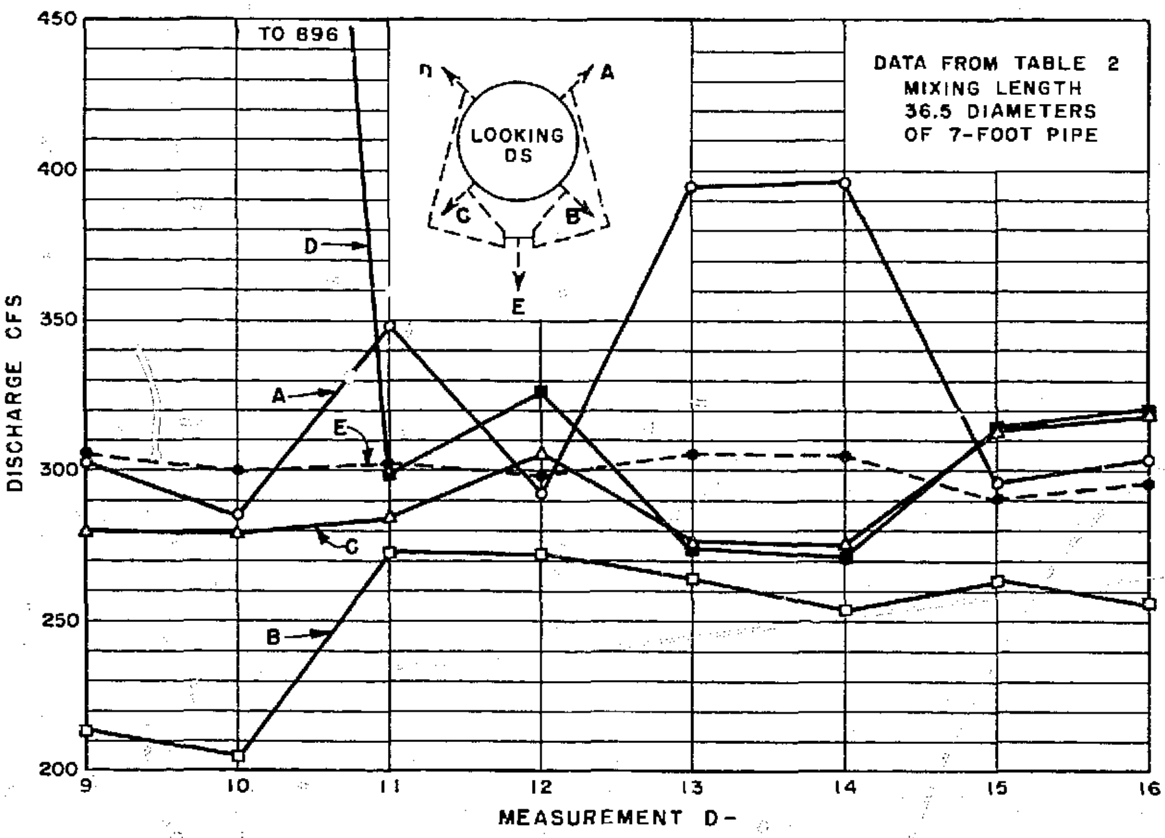
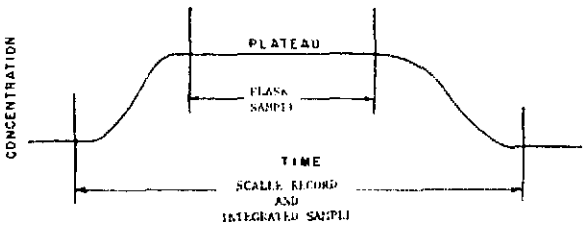


Figure 11. Discharges measured by radioisotope–Dilution method.

*Numbering continued from dilution measurements in 1968.

The last sample from each injection was extracted at the entrance to the turbine. No suitable monitor was available for determining the tracer plateau from the small flow rate of the sample. Therefore, data from measurements made in previous studies were used to compute the tracer travel time from injection to sampling. In the first four measurements, Sample G, the computations showed a discharge larger than expected. A shortening of the plateau of constant rate injection was caused by a longitudinal diffusion of the tracer.



The time allowed for sampling exceeded the plateau time and resulted in a dilution of the tracered sample. The diluted sample indicated a larger than actual discharge. To compensate, the sampling time was decreased in measurements 13 to 16 by delaying the start of the sample and ending the sample earlier. Instead of a 3-minute sampling period, a 1-minute sample was obtained at the same flow rate of 1.5 gallons per minute (gpm) (0.09 liter per second). A 1.5-gallon (5.7-liter) sample was sufficient to prepare a flask for counting.

Agreement among discharges (D–13 to 16) computed from Sample G, Table 2 was very good to within 1 percent. This agreement was expected because of the long mixing length and the improved counting techniques. The variation was slightly wider among the discharges computed from Sample G and those from the flowmeter, up to 4 percent, Measurement 16.

Conclusions from Flatiron Measurements

The variation in the discharge computed for the maximum mixing length in the pipeline indicated for D–13 to 16 that sampling and counting techniques are developed to a satisfactory degree of precision. A monitoring system or longer injection periods would be necessary to assure that a sample was obtained during the plateau time.

Discharge measurements made with mixing lengths in the order of 30 to 40 diameters of pipe indicated inadequate mixing. Both the 4-point injection and 4-point sampling of the tracer occurred in the same angular locations in the pipeline. No opportunity was available to rotate either the injection or sampling with respect (e.g. 90°) to each other. Such rotation may have indicated larger discharges because of possible deficiencies of tracer in these quadrants of the pipe. A greater number of samples taken from the pipe cross section or a greater number of injection points could possibly improve the accuracy of the discharge measurement. To meet the program objectives of simplicity, minimum interference, and the constraint of performing the measurements with existing conditions in the pipeline, the study was limited to 4-point injection and sampling near the wall of the pipe. This number of locations was not sufficient to attain a plus or minus 3/4 of 1 percent inaccuracy of measurement. Additions to the injection or sampling equipment for short pipe lengths reduces the feasibility of making measurements quickly and with a minimum of interference with powerplant operations. An additional number of injection and sampling holes placed in new structrues could improve the possibility of accurate measurements.

DEMONSTRATION AT POLE HILL POWERPLANT

Measurement Facilities

A single turbine and generator were installed in the Pole Hill Powerplant as part of the Colorado-Big Thompson Project. The Plant develops 47,500 horsepower for a discharge of 550 cfs (15.7 cu m/sec) at 815 feet (249 m) of head. Water is supplied from a gated inlet structure through an 8-foot (2.44-m) diameter, 2,044-foot (623-m) long penstock, Figures 12 and 13.

Equipment for dilution and measuring the radioisotope quantities for the discharge measurements was installed at the Pole Hill Powerplant site. A building located about 500 feet from the plant served as a field laboratory, Figure 14. The radioisotope shipment was received in Denver and transported in the mobile nuclear laboratory to the field site. All dilutions, calibrations, and radiation counting of the samples was performed in or near the powerplant. Prepared quantities of isotope to be injected for discharge measurements were transported from the powerplant to the penstock gate structure in a shielded compartment of a station wagon, Figure 15.

Radioisotope injections were made through a "ring" manifold upstream from the entrance to the penstock in the gate structure, Figures 12 and 16. The manifold was constructed from 3/4-inch (1.9-cm) electrical conduit. Forty, 1/16-inch (1.6-mm) holes were drilled in the face on one side of the ring, Figure 16. This number of holes

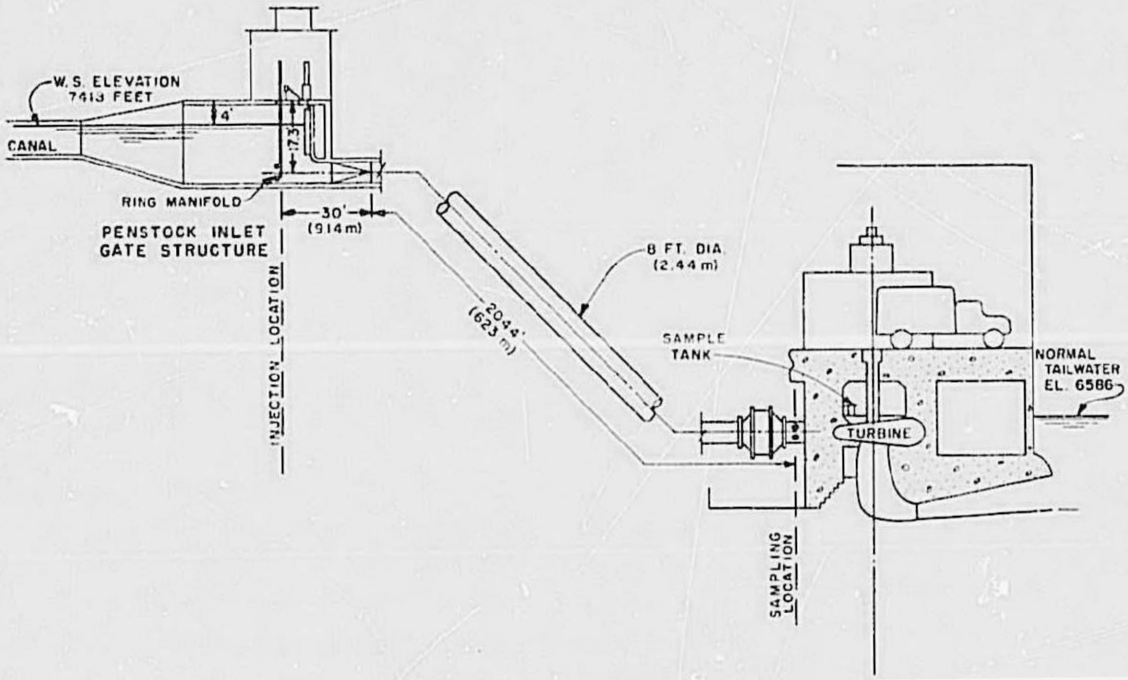


Figure 12. Pole Hill Powerplant and penstock section—Injection and sampling locations.

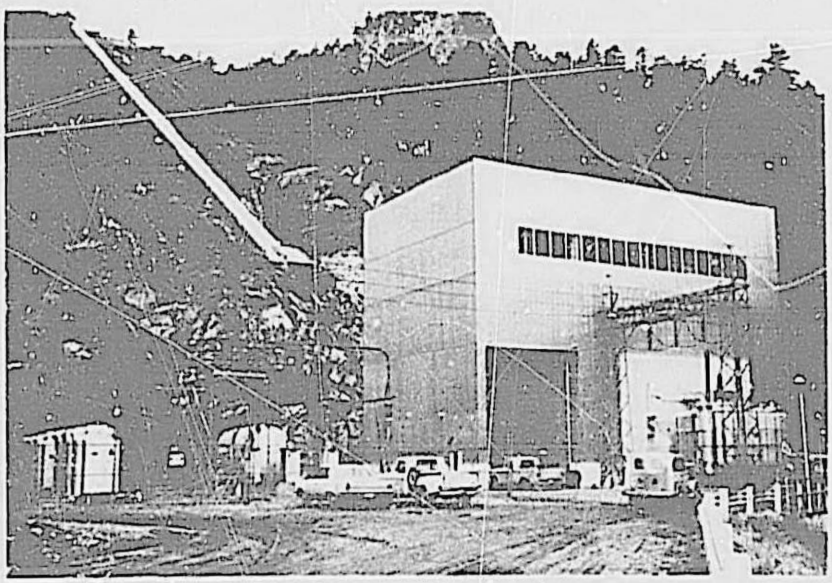
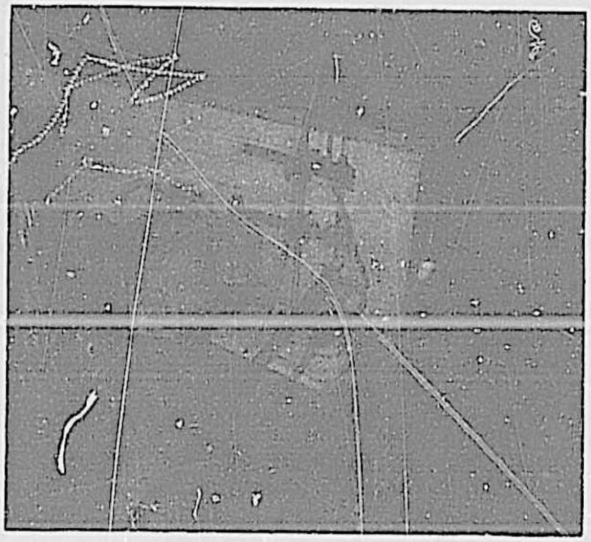
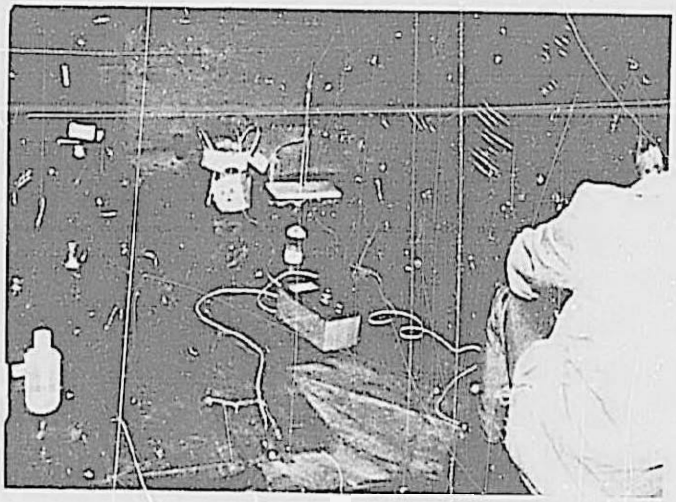


Figure 13. Pole Hill Powerplant and part of 8-foot-diameter penstock. Photo P245-D-67541



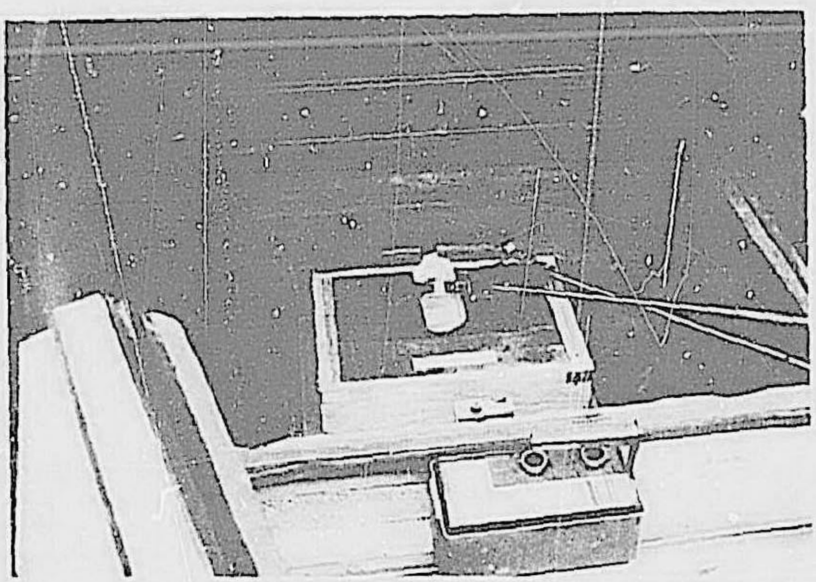
Radioisotope preparation equipment in Denver Office hot laboratory. Photo 245-D-65587



Radioisotope equipment located in building near Pole Hill Powerplant. Photo P245-D-67542

Figure 14. Radioisotope dilution apparatus in office and field laboratory.

Field laboratory building--Radiotracer quantity being placed in shielded compartment of a station wagon for transfer to penstock gate structure. Photo P245-D-67543



Shielded compartment in station wagon and plastic bottle for radioisotope. Photo P245-D-65588

Figure 15. Radioisotope transfer to injection location.

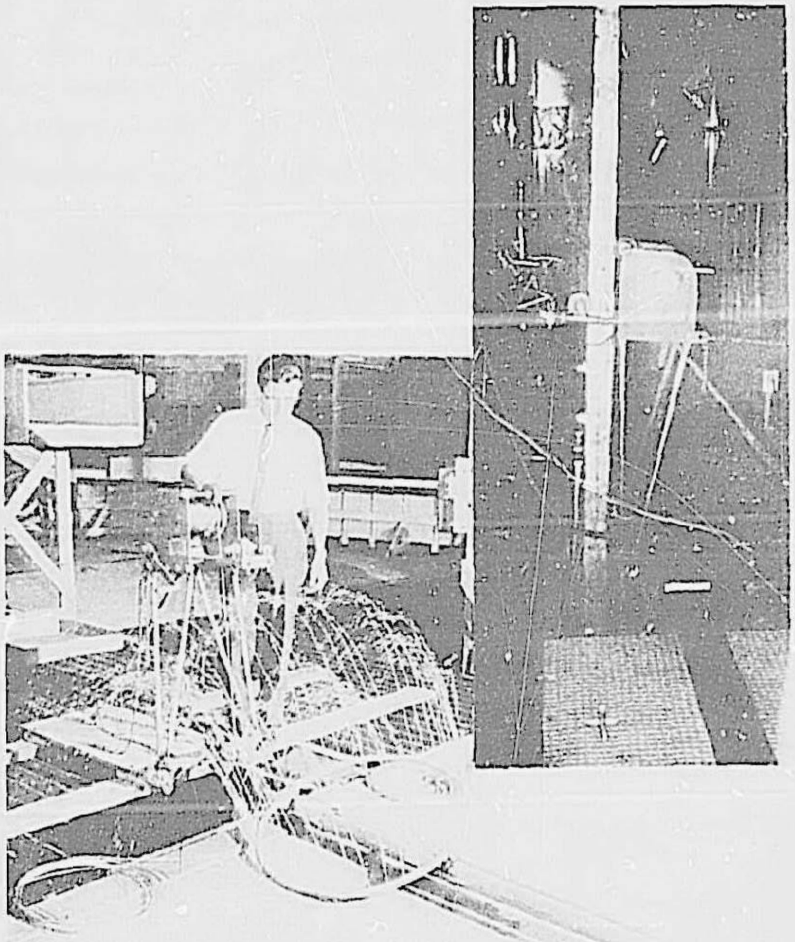


Figure 16. Laboratory operation of injection manifold and installation in penstock gate structure. Left Photo PX-D-67545, right Photo PX-D-67544

would discharge water at the rate of 6 gpm (0.38 liters per second) at 15 feet of head (4.6 meters).

The manifold was inserted into the flow with the aid of a winch and airfoil-shaped rod designed for a propeller current meter system, Figure 16. The winch was installed over a hatchway and the manifold attached to the rod was lowered into the flow. A rubber hose connected the manifold to a water pump, Figure 17.

Water was pumped from near the gate chamber water surface down to the manifold located on the penstock entrance centerline 13.3 feet (4 m) below, Figure 12. Radiotracer was added to the pumped flow near the pump outlet, Figure 17. The mixture was carried down the hose through the manifold and into the penstock. The tracer was swept directly from the manifold into the penstock without circulating in the gate chamber.

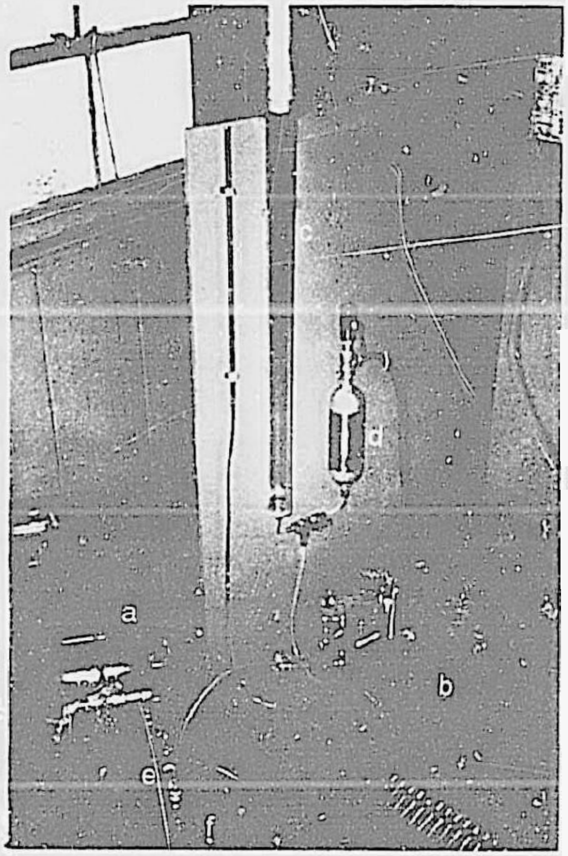


Figure 17. Radioisotope injection system–(a) water pump; (b) tracer pump; (c) tracer buret; (d) purge cylinder; (e) tracer inflow to pumped water, and (f) hose to manifold. Photo PX-D-67546

A diaphram-type pump operated at 230 strokes per minute from 110-volt, 60-Hz supply line was used to force the radiotracer into the pump flow, Figure 17. 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 graduated buret for the radiotracer was placed above and connected to the pump intake. The buret was supplied with a small air inlet at the bottom. Air was bubbled into the buret by a syringe bulb to mix the tracer and diluting water. The tracer injection rate was about 2.5 milliliters per second. A visual monitoring of the buret outflow was used to assure the constancy of the injection rate and to compute the average injection rate.

A water purge cylinder pressurized by hand-pumped air was connected near the outlet of the buret. The cylinder provided water to completely flush the tracer from the diaphram pump into the water pump flow, Figure 17.

Discrete and flow-through samples were obtained from the penstock near the turbine entrance, Figure 18. A 3/4-inch (1.9-cm) pipe manifold fed by 4-1/4-inch (0.64-cm) holes was attached to a pressure reducer. The pressure reducer, described in previous reports, provided a flow of about 20 gpm (1.3 liters per second) to a sample tank.

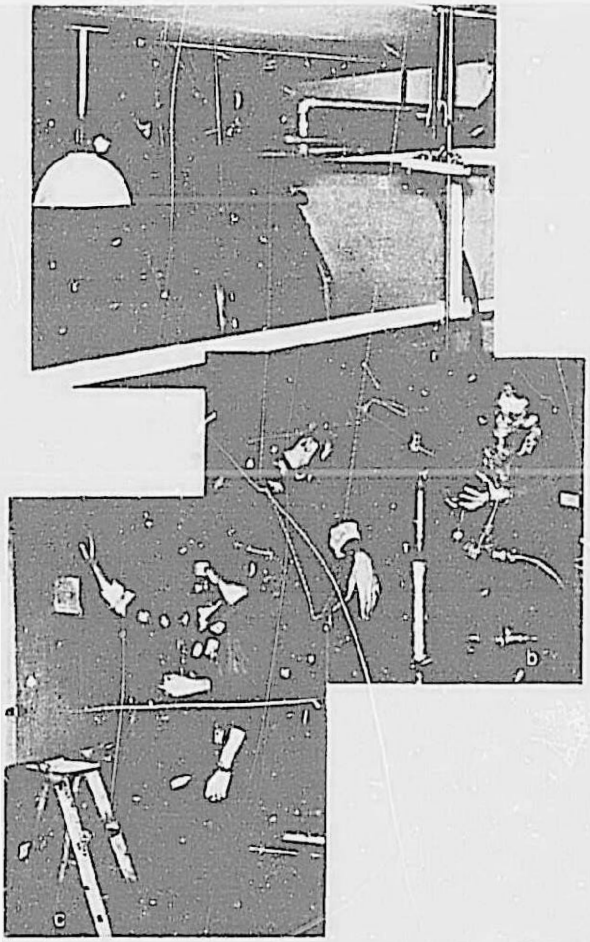


Figure 18. Sampling system–(a) sampling from turbine inlet; (b) sample tank; and (c) discrete sample containers shielded from sample tank by distance and concrete wall. Top Photo PX-D-67547, middle Photo PX-D-67548, bottom Photo PX-D-67549

Three samples were extracted near the entrance to the total-count sample tank, Figure 18. The three samples included the increasing, the plateau, and the decreasing part of the concentration of tracer-penstock water mixture, see page 11.

A water sample for radiation background was obtained for each of the discharge measurements.

A radiation counting system using the sample tank was operated from the mobile nuclear laboratory parked inside the powerplant, Figure 19. A shielded flask counting system was installed one floor below where ample shielding could be maintained between counting systems and samples, Figure 20. The radiation count from the sample tank and discrete samples provided data for computing the discharge by the total count, integrated sample, and dilution methods of measurement.

Results of Discharge Measurement

No definite superiority was indicated by any of the three radioisotope methods used to measure the discharge. The discharges for Measurements PH–1, PH–3, and PH–4 showed fairly consistent results, Table 5. In PH–1 the dilution method gave a discharge value about 2 percent lower than the total-count and integrated sample.

In Measurement PH–2, the total count agreed well with the previous measurement, the dilution was too high indicating an error in sampling and/or counting,

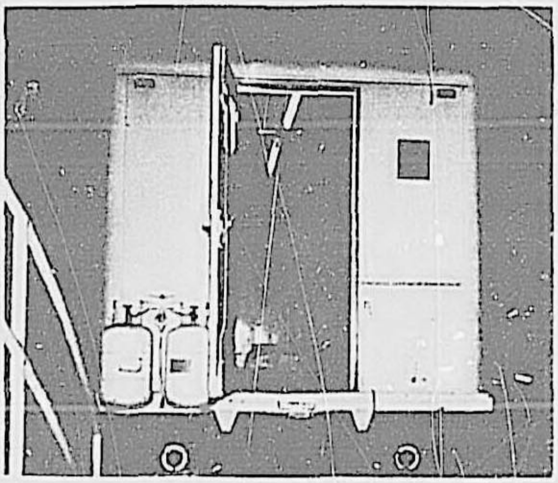


Figure 19. Mobile nuclear laboratory inside powerplant (stair to top of generator on left). Photo PX-D-67550

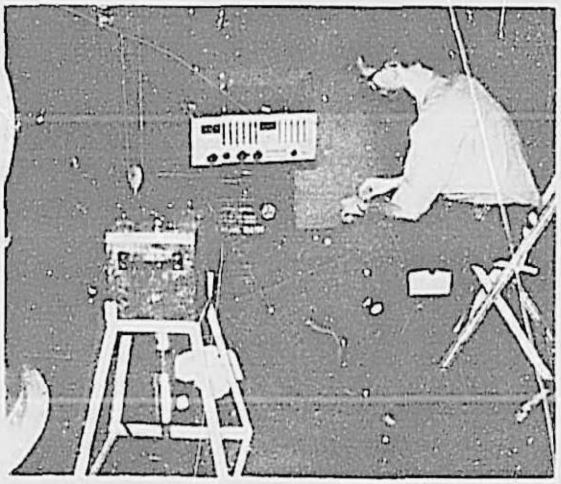


Figure 20. Shielded flask counting system one floor below mobile laboratory. Photo PX-D-67551

Table 5

RADIOISOTOPE DISCHARGE MEASUREMENTS
POLE HILL POWERPLANT DEMONSTRATION

Date August 1969	Measurement number	Total count	Dilution method	Integrated sample	Spiral case flowmeter
29	PH–1	391*	384	392	399
		(11.1)**	(10.9)	(11.1)	(11.3)
29	PH–2	391	401	–	398
		(11.1)	(11.4)	(–)	(11.3)
30	PH–3	389	393	392	398
		(11.0)	(11.1)	(11.1)	(11.3)
30	PH–4	390	392	395	397
		(11.0)	(11.1)	(11.2)	(11.2)

*Cubic feet per second
**Cubic meters per second

and the sample for the integrated sample was lost because a part of the sample was mistakenly discarded.

A difference of about 1 percent occurred for the discharges computed by the three methods in PH–3. The difference increased to about 1.3 percent in the measurements of PH–4.

The discharge computed by the total-count method were consistent, varying by about 0.5 percent. The deviation was the same as indicated by the spiral case flowmeter.

The spiral case flowmeter of the turbine had been rated during 1969. Two current-meter gaging stations had been established in open channels upstream from the powerplant. Measurements for these stations agreed to within about 1 percent. The flowmeter discharge in Table 5 was obtained from a spiral case flowmeter built by project personnel. The flowmeter related the differential of a 20-inch sloping-tube mercury manometer to the current meter ratings. An analog recorder continually charted the indicated discharge in cubic feet per second during each of the radioisotope measurements.

A difference of about 1.5 percent based on an approximate average of 392 cfs (11.1 cu m/sec) for the radioisotope method and 398 cfs (11.3 cu m/sec) for the flowmeter was observed between the two methods. This difference appears to be within the error expected for about 95 percent confidence in either the radioisotope or flowmeter measurement systems.

Conclusions from Pole Hill Measurements

The demonstration of the radioisotope method at Pole Hill Powerplant was satisfactory but indicated minor improvements still may be necessary in procedures. Deviations between the radioisotope methods may be reduced by further refinement of sampling and counting techniques. These measurements indicate that with 255 pipe diameters of mixing length, multiple injection points, and a stable counting system, discharge measurements can be made with radioisotopes to an accuracy within an estimated probable 2σ error of 1.5 percent.

The time required to make measurements is large as compared with that for the salt velocity and pressure momentum methods.[1] The time required for installation of injection and sampling equipment is less than salt velocity. Automation of both methods might lessen the time factor in favor of the radioisotope.

APPLICATION

The methods and procedures developed in the program for discharge measurement may be used for closed and in some cases open conduits wherever radioisotopes are applicable. Procedures written in a publication under the title "Recommended Procedures and Equipment for Radioisotope Discharge Measurement in High-Head Hydraulic Machines," TID-25499, resulting from these studies should be carefully followed to obtain the maximum accuracy and precision. The method is considered to be a technique of measurement for intermittent use and not one for continuous discharge measurement.

[1] TID-25177, "Discharge Measurements Using Radioisotopes in High Head Turbines and Pumps at Flatiron Power and Pumping Plant," December 1968, Appendix I.

APPENDIX

FLATIRON POWER PLANT MEASUREMENTS

TABLE 3 MEASUREMENTS D-9 TO D-12

TABLE 4 MEASUREMENTS D-13 TO D-16

Table 3A

MEASUREMENTS D-9 TO D-12

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PESTØCK #2
N

RUN	SAMPLE	DATE	FLØW CF/S	TØTAL STATISTICAL CØUNTING ERRØR
D-9	A	08/06/69	302.78	0.41 PCT
D-9	B	08/06/69	213.22	0.36 PCT
D-9	C	08/06/69	277.89	0.39 PCT
D-9	D	08/06/69	836.95	0.77 PCT
D-9	E	08/06/69	304.79	0.46 PCT
D-9	F	08/06/69	310.62	0.47 PCT
D-10	A	08/06/69	284.83	0.4 PCT
D-10	B	08/06/69	204.7	0.44 PCT
D-10	C	08/06/69	279.48	0.39 PCT
D-10	D	08/06/69	896.12	0.79 PCT
D-10	E	08/06/69	300.19	0.46 PCT
D-10	F	08/06/69	302.19	0.46 PCT
D-11	A	08/07/69	348.06	0.4 PCT
D-11	B	08/07/69	273.42	0.44 PCT
D-11	C	08/07/69	284.43	0.36 PCT
D-11	D	08/07/69	298.35	0.39 PCT
D-11	E	08/07/69	302.23	0.45 PCT
D-11	F	08/07/69	302.92	0.39 PCT
D-12	A	08/07/69	292.54	0.36 PCT
D-12	B	08/07/69	271.57	0.42 PCT
D-12	C	08/07/69	306.46	0.36 PCT
D-12	D	08/07/69	326.56	0.39 PCT
D-12	E	08/07/69	298.3	0.44 PCT
D-12	F	08/07/69	300.05	0.38 PCT

Table 3B

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PENSTØCK #2

BR-82 ACTIVITY REFERED TØ: 08/04/69 10:00

INJECTIØN DATA:

RUN	DATE	CØNC. UC/ML	INJ. RATE ML/S	REMARKS
D-9	08/04/69	59.278	7.018	P = 65 PSID
D-10	08/04/69	59.278	6.897	
D-11	08/04/69	95.436	7.977	
D-12	08/04/69	95.436	8.882	

SENSITIVITY AND DEADTIME:
DØ-7 F = 307.29 1/S/UC/CF +- 0.342 PCT T = 3.05 USEC
DØ-8 F = 305.07 1/S/UC/CF +- 0.256 PCT T = 1.92 USEC

CØUNTING DATA:

RUN	SAMPLE	DATE	START TIME	CØUNTER	GRØSS	TIME (SEC)	BGND	TIME (SEC)
D-9	A	08/06/69	16:46	DØ-8	239438	1320	23274	600
D-9	B	08/06/69	14:17	DØ-8	256602	1020.1	23274	600
D-9	C	08/06/69	16:20	DØ-8	246365	1260	23274	600
D-9	D	08/06/69	16:58	DØ-7	137447	1499.9	23944	600.1
D-9	E	08/06/69	14:15	DØ-7	250439	1320	23944	600.1
D-9	F	08/06/69	17:53	DØ-7	243237	1370	26808	660
D-10	A	08/06/69	15:13	DØ-8	230911	1200	23274	600
D-10	B	08/06/69	15:47	DØ-7	252858	1000	23944	600.1
D-10	C	08/06/69	15:40	DØ-8	244423	1260.2	23274	600
D-10	D	08/06/69	15:15	DØ-7	147266	1654.9	23944	600.1
D-10	E	08/06/69	16:14	DØ-7	249883	1360	23944	600.1
D-10	F	08/06/69	17:27	DØ-7	246776	1370	26808	660
D-11	A	08/07/69	14:26	DØ-8	222943	1199.8	26888	720
D-11	B	08/07/69	15:28	DØ-7	272572	1200.1	24377	600
D-11	C	08/07/69	13:34	DØ-8	266566	1200	26888	720
D-11	D	08/07/69	15:20	DØ-8	255364	1200	25582	600.1
D-11	E	08/07/69	14:42	DØ-7	254286	1200	24377	600
D-11	F	08/07/69	16:11	DØ-8	248952	1200	25582	600.1
D-12	A	08/07/69	14:52	DØ-8	278847	1200	26888	720
D-12	B	08/07/69	15:51	DØ-7	297661	1200	24337	600
D-12	C	08/07/69	14:00	DØ-8	272011	1200	26888	720
D-12	D	08/07/69	15:45	DØ-8	257181	1200	25582	600.1
D-12	E	08/07/69	15:05	DØ-7	278792	1200	24337	600
D-12	F	08/07/69	16:49	DØ-8	270752	1200	25582	600.1

Table 3C

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PENSTØCK #2

RUN	SAMPLE	DATE	FLØW* CF/S	TØTAL STATISTICAL CØUNTING ERRØR
D-9	G	08/06/69	325.08	0.43 PCT
D-10	G	08/06/69	317.82	0.43 PCT
D-11	G	08/07/69	375.21	0.48 PCT
D-12	G	08/07/69	368.46	0.45 PCT

DILUTIØN FLØW MEASJREMENTS
FLATIRØN P.P. -- PENSTØCK #2

BR-82 ACTIVITY REFERED TØ: 08/04/69 10:00

INJECTIØN DATA:

RUN	DATE	CØNC. UC/ML	INJ. RATE ML/S	REMARKS
D-9	08/04/69	59.278	7.018	P = 65 PSID
D-10	08/04/69	59.278	6.897	
D-11	08/04/69	95.436	7.977	
D-12	08/04/69	95.436	8.882	

SENSITIVITY AND DEADTIME:
DØ-7 F = 307.29 1/S/UC/CF +- 0.342 PCT T = 3.05 USEC
DØ-8 F = 305.07 1/S/UC/CF +- 0.256 PCT T = 1.92 USEC

CØUNTING DATA:

RUN	SAMPLE	DATE	START TIME	CØUNTER	GRØSS	TIME (SEC)	BGND	TIME (SEC)
D-9	G	08/06/69	17:14	DØ-8	214480	1260	23145	600
D-10	G	08/06/69	17:40	DØ-8	213957	1260.2	23145	600
D-11	G	08/07/69	14:20	DØ-7	215050	1200.1	24137	600.1
D-12	G	08/07/69	13:58	DØ-7	238672	1199.8	24137	600.1

Table 4A

MEASUREMENTS D-13 TO D-16

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PENSTØCK #2

RUN	SAMPLE	DATE	FLØW CF/S	TØTAL STATISTICAL CØUNTING ERRØR
D-13	A	08/13/69	395.03	0.39 PCT
D-13	B	08/13/69	264.28	0.31 PCT
D-13	C	08/13/69	279.96	0.34 PCT
D-13	D	08/13/69	274.24	0.3 PCT
D-13	E	08/13/69	305.65	0.31 PCT
D-13	F	08/13/69	296.31	0.32 PCT
D-14	A	08/13/69	396.85	0.38 PCT
D-14	B	08/13/69	253.23	0.31 PCT
D-14	C	08/13/69	274.88	0.33 PCT
D-14	D	08/13/69	272.03	0.29 PCT
D-14	E	08/13/69	305.3	0.31 PCT
D-14	F	08/13/69	294.77	0.35 PCT
D-15	A	08/14/69	295.77	0.29 PCT
D-15	B	08/14/69	262.8	0.27 PCT
D-15	C	08/14/69	312.82	0.3 PCT
D-15	D	08/14/69	313.72	0.28 PCT
D-15	E	08/14/69	290.89	0.24 PCT
D-15	F	08/14/69	295.5	0.27 PCT
D-16	A	08/14/69	304.06	0.31 PCT
D-16	B	08/14/69	256.45	0.29 PCT
D-16	C	08/14/69	318.16	0.33 PCT
D-16	D	08/14/69	321.24	0.29 PCT
D-16	E	08/14/69	296.17	0.27 PCT
D-16	F	08/14/69	280.97	0.31 PCT

Table 4B

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PENSTØCK #2

BR-82 ACTIVITY REFERED TO: 08/11/69 10:00

INJECTIØN DATA:

RUN	DATE	CØNC. UC/ML	INJ. RATE ML/S	REMARKS
D-13	08/11/69	55.2	7.3746	
D-14	08/11/69	55.2	7.4534	
D-15	08/11/69	104.855	8.7379	
D-16	08/11/69	88.868	8.8816	

SENSITIVITY AND DEADTIME:
DØ-7 F = 329.42 1/S/UC/CF +- 0.072 PCT T = 3.05 USEC
DØ-8 F = 320.77 1/S/UC/CF +- 0.16 PCT T = 1.92 USEC

CØUNTING DATA:

RUN	SAMPLE	DATE	START TIME	CØUNTER	GRØSS	TIME (SEC)	BGND	TIME (SEC)
D-13	A	08/13/69	14:22	DØ-8	185969	1200.3	26642	720.1
D-13	B	08/13/69	15:13	DØ-8	252496	1200.4	26642	720.1
D-13	C	08/13/69	16:04	DØ-8	238661	1200.2	22764	600.3
D-13	D	08/13/69	15:49	DØ-7	249030	1200	22816	600
D-13	E	08/13/69	14:15	DØ-7	232582	1200	22200	600
D-13	F	08/13/69	16:37	DØ-7	230965	1200	22816	600
D-14	A	08/13/69	14:49	DØ-8	178857	1200	22642	720.1
D-14	B	08/13/69	15:38	DØ-8	255401	1200.3	22642	720.1
D-14	C	08/13/69	16:28	DØ-8	242746	1200	22764	600.3
D-14	D	08/13/69	16:13	DØ-7	251260	1200	22816	600
D-14	E	08/13/69	14:38	DØ-7	233387	1200	22200	600
D-14	F	08/13/69	16:53	DØ-8	227997	1200.4	22764	600.3
D-15	A	08/14/69	13:56	DØ-8	313018	1200.2	22536	600
D-15	B	08/14/69	14:46	DØ-8	341717	1200.2	22536	600
D-15	C	08/14/69	15:36	DØ-8	291987	1200	23408	600
D-15	D	08/14/69	15:34	DØ-7	249598	1000	24131	600
D-15	E	08/14/69	14:48	DØ-7	321319	1200	25524	660
D-15	F	08/14/69	16:17	DØ-7	259395	1000	24131	600
D-16	A	08/14/69	14:21	DØ-8	267764	1200	22536	600
D-16	B	08/14/69	15:11	DØ-8	304850	1200.2	22536	600
D-16	C	08/14/69	16:00	DØ-8	252905	1200.3	23408	600
D-16	D	08/14/69	15:54	DØ-7	258186	1200.1	24131	600
D-16	E	08/14/69	15:11	DØ-7	277303	1200	25524	660
D-16	F	08/14/69	16:26	DØ-8	278192	1200.2	23408	600

Table 4C

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PENSTØCK #2

RUN	SAMPLE	DATE	FLØW CF/S	TØTAL STATISTICAL CØUNTING ERRØR
D-13	G	08/13/69	312.26	0.32 PCT
D-14	G	08/13/69	312.37	0.32 PCT
D-15	G	08/14/69	309.7	0.25 PCT
D-16	G	08/14/69	313.1	0.28 PCT

DILUTIØN FLØW MEASUREMENTS
FLATIRØN P.P. -- PENSTØCK #2

BR-82 ACTIVITY REFERED TØ: 08/11/69 10:00

INJECTIØN DATA:

RUN	DATE	CØNC. UC/ML	INJ. RATE ML/S	REMARKS
D-13	08/11/69	55.2	7.3746	
D-14	08/11/69	55.2	7.4534	
D-15	08/11/69	104.855	8.7379	
D-16	08/11/69	88.868	8.8816	

SENSITIVITY AND DEADTIME:
DØ-7 F = 329.42 1/S/UC/CF +- 0.072 PCT T = 3.05 USEC
DØ-8 F = 320.77 1/S/UC/CF +- 0.16 PCT T = 1.92 USEC

CØUNTING DATA:

RUN	SAMPLE	DATE	START TIME	CØUNTER	GRØSS	TIME (SEC)	BGND	TIME (SEC)
D-13	G	08/13/69	15:02	DØ-7	225799	1200	22200	600
D-14	G	08/13/69	15:25	DØ-7	226286	1199.9	22200	600
D-15	G	08/14/69	14:00	DØ-7	308699	1200	25524	660
D-16	G	08/14/69	14:24	DØ-7	268218	1200.1	25524	660

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
	0.3048 (exactly)*	Meters
	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03*	Square centimeters
	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	0.40469*	Hectares
	4,046.9*	Square meters
	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
	0.473166	Liters
Quarts (U.S.)	946.358*	Cubic centimeters
	0.946331*	Liters
Gallons (U.S.)	3,785.43*	Cubic centimeters
	3.78543	Cubic decimeters
	3.78533	Liters
	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acre-feet	1,233.5*	Cubic meters
	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^{6}	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^{7}	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-seconds per square foot (viscosity)	4.8824*	Kilogram second per square meter
Square feet per second (viscosity)	0.092903*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	35.3147*	Millicuries per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.527219*	Liters per square meter
Pounds per inch	0.17858*	Kilograms per centimeter