Meeting
Preprint 1294

AMERICAN SOCIETY OF CIVIL ENGINEERS
FOUNDED 1852

Radioisotopes and Turbine Flow Measurements

J. C. Schuster and R. L. Hansen

ASCE National Water Resources
Engineering Meeting
Phoenix, Arizona
January 11-15, 1971 / $0.50

RADIOISOTOPES AND TURBINE FLOW MEASUREMENTS

by

J. C. Schuster* and R. L. Hansen**

INTRODUCTION

During the years 1965 to 1970, the Atomic Energy Commission and Bureau of Reclamation cooperated in a research program for measuring discharge through high-head turbines and pumps using radioisotopes. The purpose was to make discharge measurements accurately, quickly, and with a minimum of personnel and equipment. One of the goals of the program was to develop the method to a precision allowing discharge measurements to be made within a probable inaccuracy of $\pm$ 3/4 of 1 percent.

The program was accomplished in five phases. Initial phases were used for an extensive search of foreign and domestic literature and produced about 300 references related to using tracers, including radioisotopes, for making pipeline discharge measurements. Theoretical and experimental studies were made of the hydraulic parameters that affect and control mixing of the tracer with the flowing water using an 8-inch and 36-inch diameter (20.3 and 91.5 cm) pipeline. Radioisotope calibration, counting, and sampling procedures were evaluated in the field and laboratory.

---

*Hydraulic Engineer, Hydraulics Branch, Division of General Research, Engineering and Research Center, Bureau of Reclamation, Denver, Colorado
**Physical Scientist, Applied Sciences, Division of General Research, Engineering and Research Center, Bureau of Reclamation, Denver, Colorado

On conclusion of these studies, discharge measurements were begun on a 6,000-foot-long (1830 m) penstock having diameters ranging from 7 to 6 feet (2.13 to 1.83 m) and a 6,000-foot pumpline having an 8-foot (2.44 m) diameter. The Flatiron Power and Pumping Plant serviced by the penstock operated under a normal head of about 1,100 feet of water (324 meters) and the pump under a head of 270 feet (80 meters).

A series of measurements was made to compare the relative accuracy of using the radioisotope-velocity (similar to the salt-velocity method), integrated sample, dilution, and total-count methods of measurement. Mixing theories and measurement procedures using radioisotopes were tested by repeating measurements over a chosen pipe length and studying the deviations among the calculated discharges.

Details of the measurements are included in References 1, 3, 5, and 6 of this paper. The fifth and final phase of the program, covered in part in this paper, was a series of measurements that summarized the techniques and procedures developed for measuring flow.

Dilution of tracers may be considered as a special technique for discharge measurements. The technique consists of adding a concentrated tracer of known strength, C_i, to the flow. By suitable analysis, the dilution is determined from sampling after the tracer has completely mixed with the flow at a downstream point. Conductivity, color, fluorescence, and radioactivity are used in the tracer methods.

In application, the tracer solution is commonly added to the flow at a constant known rate, q. The flow, Q, multiplied by its natural tracer content, C_o, and added to q times C_i, equals the discharge plus the injection discharge multiplied by the final concentration, C_2. Mathematically:

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

or

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

Thus, by measuring C_o, C_i, C_2, and q, the rate of flow, Q, may be determined without having a precise knowledge of the geometry of the conveyance.

There are several ways of applying the radiotracer method of discharge measurement. The ways include the velocity (similar to the salt-velocity method), integrated sample, dilution, and pulse methods. The last three methods utilize the dilution technique. The method selected for discharge measurements may depend on the procedure of tracer injection, by pulse, that is in a short time period, or by continuous rate over a longer period. The major difference between the methods is in the way of using the measured C_2 to compute the discharge. Details of the methods will not be covered here because many papers, including those referenced in this paper, explain the principles of application.

Investigations of the ways of application have not shown clearly a major advantage to one particular method 1/* 2/.

---

*See references listed at end of paper.

Each method has its own advantages and disadvantages and can be considered for a particular situation. For example, three sampling and radioactive counting procedures were compared for one injection procedure at a powerplant in the final phase of the AEC-USBR program 3/.

COMPARISONS AT POLE HILL POWERPLANT

Measurement Facilities

A single turbine and generator unit was installed in the Pole Hill Powerplant. The plant, a feature of the Bureau of Reclamation's Colorado-Big Thompson Project, develops 47,500 horsepower (48,200 metric horsepower) for a discharge of 550 cfs (15.7 cms) 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 (255 pipe diameters).

Equipment for diluting 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. 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.

The radioisotope used in the test was Bromine-82 as KBr in a water solution. The concentrated solution received from the production facility was diluted with water at the field site. All quantities of the tracer solution used for injection and calibration were measured gravimetrically to circumvent the need for temperature correction in volumetric measurement.

Radioisotope injections were made through a "ring" manifold upstream from the entrance to the penstock in the gate structure, Figure 1. 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. This number of holes would discharge water at the rate of 6 gallons per minute (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. 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.

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 the water surface, Figure 2.

Radiotracer was added to the pumped flow near the pump outlet 4/. 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.

A diaphragm-type pump operated at 230 strokes per minute from 110-volt, 60-Hz supply line was used to force the radiotracer (^{82}Br) into the pump flow. 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 diaphragm.

A graduated buret for the radiotracer was placed above the pump and connected to the intake. The bottom of the buret was equipped with a small air inlet. Air was bubbled into the buret by a syringe bulb to mix the tracer and diluting water. The tracer injection rate from the pump 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 diaphragm pump into the water pump flow 3/.

Discrete and flow-through samples were obtained from the penstock near the turbine entrance, Figure 3.

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 sampling tank 5/.

Three discrete samples were extracted near the entrance to the total-count sampling tank. The three samples included the increasing, the plateau, and the decreasing part of the concentration of tracer-penstock water mixture, Figure 4.

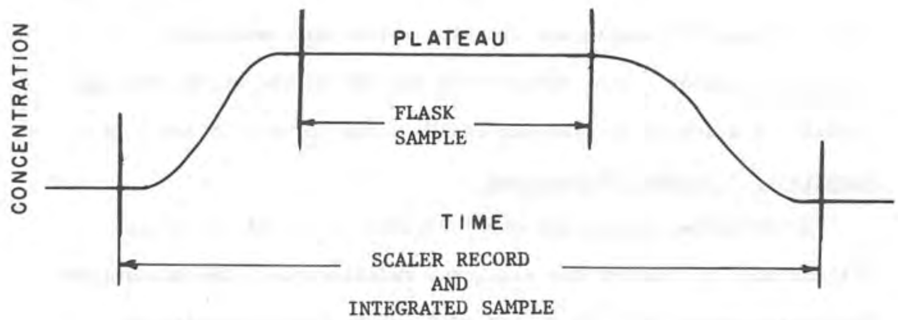


Figure 4

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. A shielded flask-counting system was installed one floor below where ample shielding could be maintained between counting systems and samples 3/. The radiation count from the sampling tank and discrete samples provided data for computing the discharge by the total count or pulse, integrated sample, and dilution methods of measurement.

The sample tank detector was an integral line scintillation counter with a 1-1/2-inch-diameter by 1-inch-thick NaI(TI) crystal. A solid state preamplifier provides signal amplification to drive the signal to the scaling units located in the mobile nuclear laboratory. Discrete 2-liter samples taken for computing discharge by the integrated sample and dilution method were measured by a separate detector. This detector is similar to the above, but the crystal is 3 inches in diameter and 2 inches thick (7.6 and 5 cm).

Results of Discharge Measurement

No definite superiority was indicated by any of the three methods used to measure the discharge radioisotope. The discharges for Measurements PH-1, PH-3, and PH-4 showed fairly consistent results, Table 1.

Table 1

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

In PH-1 the dilution method gave a discharge value about 2 percent lower than the total-count and integrated sample methods.

In Measurement PH-2, the total-count agreed well with the previous measurement, the result of the dilution method was too high indicating an error in sampling and/or counting, and the measurement for the integrated method 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 discharges 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. Flow measurements at these stations agreed within about 1 percent. The flowmeter discharge in Table 1 was obtained from a spiral case flowmeter built by project personnel. The flowmeter related the differential of a 20-inch (50.8 cm) 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 cms) for the radioisotope method and

398 cfs (11.8 cms) for the flowmeter occurred 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.

These measurements indicated that with 255 pipe diameters of mixing length, multiple injection points, four sampling points in the pipe wall, and a stable counting system, discharge measurements could be made with radioisotopes to an accuracy within an estimated 2 sigma error of 1.5 percent, about two times the program goal.

GENERAL OBSERVATIONS

Velocity method. - There appear to be two major causes of deviations among discharges measured by the velocity method in Phase IV of the program not described herein but in Reference 1.

a. A single detector used at a sampling station for recording the tracer passage produces an irregular recording of the count rate because of the short mixing length between the injector and detectors.

b. The nonuniform count rate makes computing the center of area of the tracer-water mixture difficult. Thus, establishing the flow time between detectors cannot be done accurately causing errors in computing the discharge.

Multiple detectors, three or more at each of the two sampling sections, improves the averaging of the radiation count and computation of the center of area of the tracer-water mixture in the pipeline. An accurate measure of the volume of the pipeline between the detector array must be made for an accurate discharge measurement. This method normally uses the least amount of radioactivity.

Integrated-sample method. - The ultimate accuracy of the integrated-sample method may be limited by the pulse type of injection used for the method. A sampling of the pulse of tracer-water mixture from single points 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 1/.

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

The counting accuracy for flask samples was higher than for scaler records but the standard deviations of the measurements were about the same. A detector with greater sensitivity used in a sampling tank probably could produce a high counting and discharge measurement accuracy. Refinement of the procedures could eliminate the need for collecting a sample to be counted in a flask.

Care should be exercised in selecting counting flasks. Differing glass quality causes variation in the counting rate for the flasks used in dilution measurements. The variation may be caused by irregularities in thickness of the glass bottom which is almost in direct contact with the detector crystal.

The dilution and integrated sample methods 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 or total-count methods where no sample is retained. The longer time and additional injection equipment 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 mixed over the 919 diameters indicated the longer mixing distance 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) mixing lengths.

General. - Mixing lengths of 100 pipe diameters or more appear to produce the higher accuracies of measurements for single-point injection and single-point sampling. Discharges computed from measurements at 36.5 and 100 diameters show about the same deviation when compared to spiral case flowmeters. The mixing of the tracer with the flowing water was improved in the shorter length by injection near the wall of the pipe from four points in the cross section and sampling from four holes 90° apart connected to withdraw a single sample. The agreement of discharges for the two mixing lengths would indicate that for multiple point injection, a shorter mixing length can be used if multiple samples are blended into one sample or are averaged from multiple samples. The minimum number of samples was not determined.

For the radioisotope methods used in these studies, there were certain discharge values that exceeded the error that could be estimated for procedures and equipment used in these measurements. The sources of the larger errors were not completely found, but 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.

One problem of particular interest to those studying fluid mechanics and to this program is a rigorous investigation of the natural and artificial diffusion of the tracer in pipe flow. Discharge measurements of high accuracy require:

1. A large number of samples or

2. A sample of a tracer-water mixture having a coefficient of variation of concentration at the sampling point of less than 0.1 percent to produce a mixing percentage of 99.9 percent.

At program completion, the 2 sigma error of the radioisotope method, including procedures and equipment, was estimated to be ± 1.5 percent.

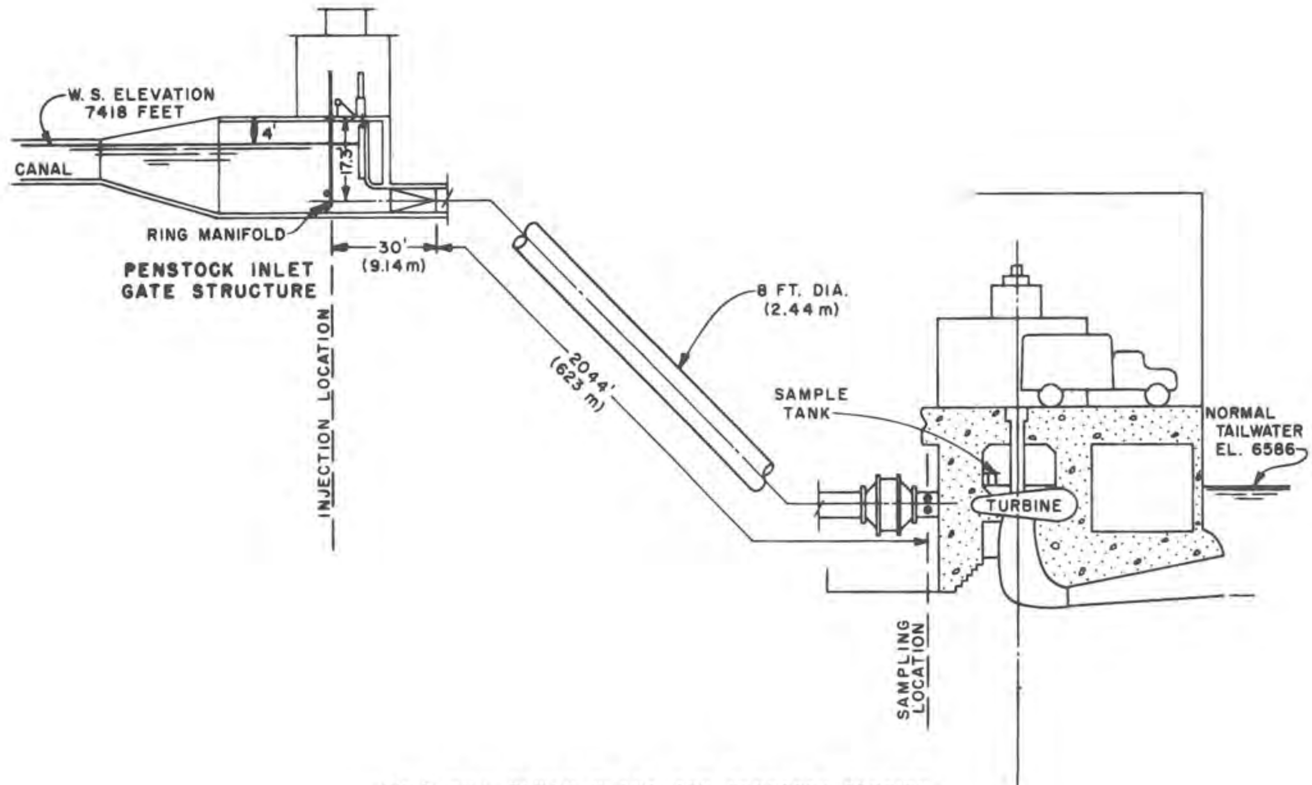
APPLICATIONS

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 by the Bureau for the AEC in a publication under the title "Recommended Procedures and Equipment for Radioisotope Discharge Measurement in High-Head Hydraulic Machines" 6/ 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.

Appendix: REFERENCES

1. "Discharge measurements using the radioisotope velocity, integrated sample, dilution, and total-count methods at Flatiron Power and Pumping Plant," J. C. Schuster, R. L. Hansen, Bureau of Reclamation, U.S. Atomic Energy Commission - Division of Technical Information, Report No. TID25185, 1969.

2. "The constant-rate injection and velocity methods of flow measurement for testing hydraulic machines," C. G. Clayton, G. V. Evans, Isotope Research Division, Wantage Research Laboratory (A.E.R.E.), England, Report No. AERE-R5872, 1968.
3. "Discharge measurements using radioisotopes at Flatiron and Pole Hill Powerplants," J. C. Schuster and R. L. Hansen, Bureau of Reclamation, U.S. Atomic Energy Commission, Division of Technical Information Report No. TID25395, 1970.
4. "The use of a pump to reduce mixing length in the dilution method of flow measurement," C. G. Clayton, Isotope Research Division, Wantage Research Laboratory (A.E.R.E.), Report No. AERE-R4623, 1964.
5. "Discharge measurements using radioisotopes in high-head turbines and pumps at Flatiron power and pumping plant," J. C. Schuster and R. L. Hansen, Bureau of Reclamation, U.S. Atomic Energy Commission - Division of Technical Information, Report No. TID-25177, Appendix 1.
6. "Recommended procedures and equipment for radioisotope discharge measurement in high-head hydraulic machines," R. L. Hansen and G. A. Teter, U.S. Atomic Energy Commission - Division of Technical Information, Report No. TID-25499.



POLE HILL POWER PLANT AND PENSTOCK SECTION

INJECTION AND SAMPLING LOCATIONS

FIGURE 1

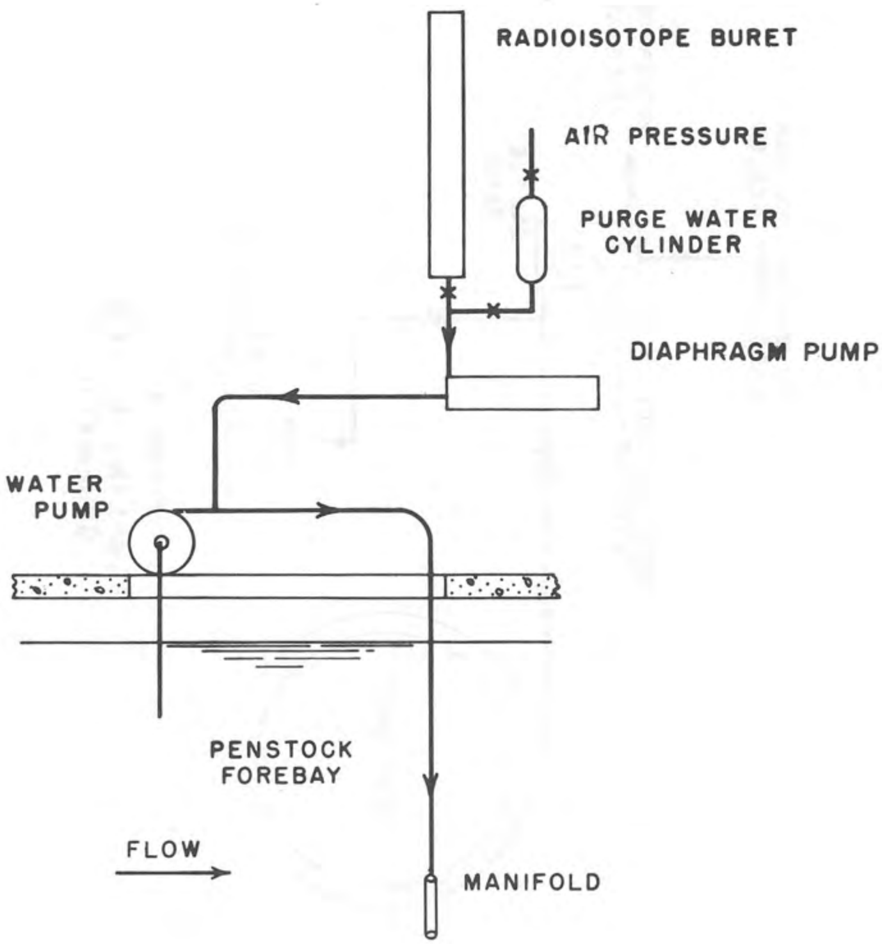


FIGURE 2
INJECTION SYSTEM SCHEMATIC

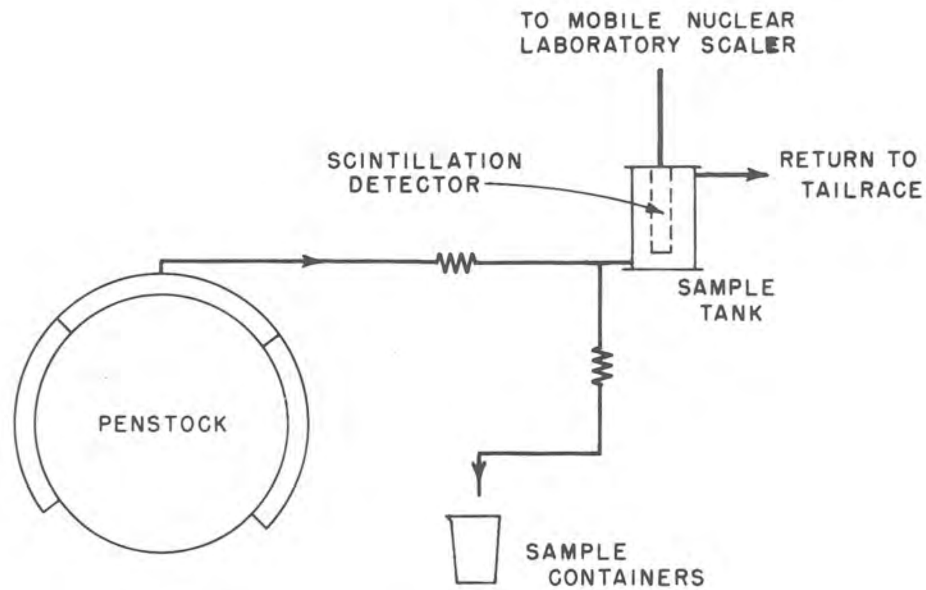


FIGURE 3

SAMPLING SYSTEM SCHEMATIC