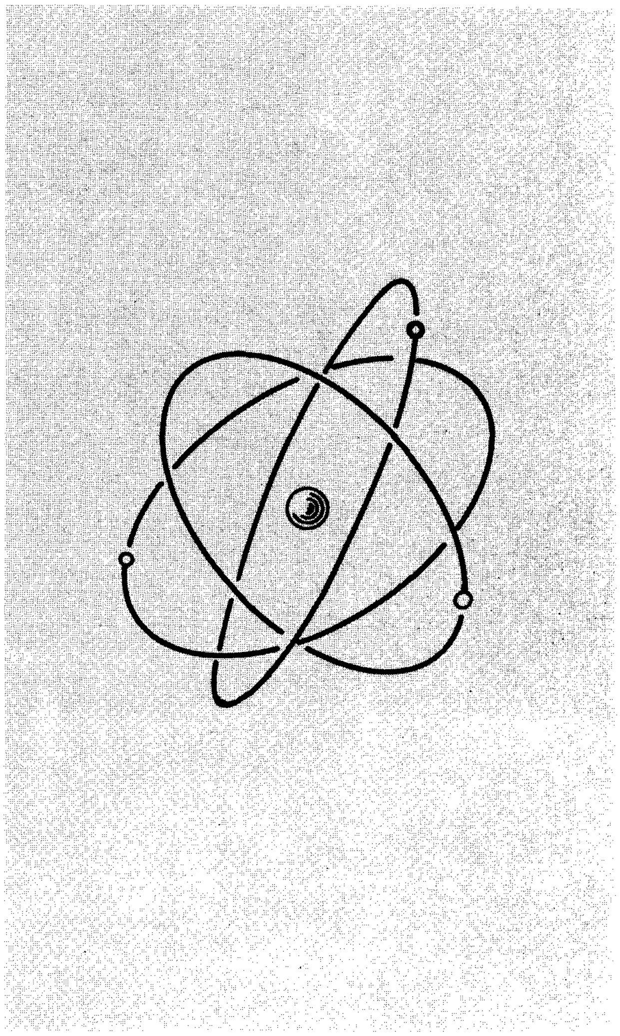
A WATER RESOURCES TECHNICAL PUBLICATION
ENGINEERING MONOGRAPH NO. 38



Potential Economic Benefits from the Use of Radioisotopes in Flow Measurements Through High-Head Turbines and Pumps

UNITED STATES DEPARTMENT
OF THE INTERIOR
BUREAU OF RECLAMATION

A WATER RESOURCES TECHNICAL PUBLICATION

Engineering Monograph No. 38

Potential Economic Benefits From the Use of Radioisotopes in Flow Measurements Through High-Head Turbines and Pumps

By EDMUND BARBOUR

Divison of Project Investigations
Office of Chief Engineer, Denver, Colorado

United States Department of the Interior • Walter J. Hickel, *Secretary*

BUREAU OF RECLAMATION

Floyd E. Dominy, *Commissioner*

B. P. Bellport, *Chief Engineer*

As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources."

The Department works to assure the wisest choice in managing all our resources so each will make its full contribution to a better United States—now and in the future.

ENGINEERING MONOGRAPHS are prepared and used by the technical staff of the Bureau of Reclamation. In the interest of dissemination of research experience and knowledge, they are made available to other interested technical circles in Government and private agencies and to the general public by sale through the Superintendent of Documents, Government Printing Office, Washington, D.C.

First Printing: 1969

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON : 1969

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, or the Chief Engineer, Bureau of Reclamation, Attention 841, Denver Federal Center, Denver, Colo. 80225. Price 45 cents.

Preface

THIS REPORT presents a "broad-brush" study which identifies the economic potentials of radioisotopes in measuring high-pressure waterflows through hydraulic turbines and pumps. There is general agreement that a need exists for a highly accurate, simple, and inexpensive means for measuring flows. No doubt, other promising alternative measuring devices not employing radioisotopes may warrant further consideration.

The main question in this report is not whether the radioisotope method will prove technically successful, but rather what are reasonable expectations of the benefits to be gained if this potential new tool successfully meets its goals? The report indicates that the possible economic gains from application to the Bureau of Reclamation program are attractive. This would logically apply not only to the use of radioisotopes, but to other approaches if the same objectives were served.

Special acknowledgment is due for the contributions made by Messrs. Robert L. Hansen, Chemical Engineering Branch, and Jack C. Schuster, Hydraulics Branch. Valuable assistance on the estimates of the costs of acceptance tests was provided by Mr. George H. Johnson, Hydraulic Machinery Branch. Numerous others cooperated in the study, including members of the Hydraulic Machinery and Technical Engineering Analysis Branches of the Division of Design, Division of Power Operations, and Division of Irrigation Operations.

Included in this publication is an informative abstract with a list of descriptors, or key words, and "identifiers." The abstract was prepared as part of the Bureau of Reclamation's program of indexing and retrieving the literature of water resources development. The descriptors were selected from the *Thesaurus of Descriptors*, which is the Bureau's standard for listing of key words.

Other recently published Water Resources Technical Publications are listed on the inside back cover of this report.

Contents

TABLES

FIGURES

Summary

THE BUREAU OF RECLAMATION and Atomic Energy Commission are cooperating in research to determine the feasibility of using radioisotopes for measuring waterflows through high-pressure turbines and pumps to meet a well-established need for a method which is highly accurate, simple, and inexpensive to apply. Achievement of this goal would provide an improved tool not now available. The possibilities for realizing economic gains from such a development were studied using the Bureau of Reclamation's program as a basis for analysis, although there would be opportunities for broader application both nationally and internationally.

A brief appraisal of alternative methods now used in gaging high-pressure waterflows indicated that the pressure-time (Gibson) and the salt-velocity methods are in predominant use by the Bureau, with the former favored but applicable to turbines only. A projection of field application procedures and hardware requirements suggests that substantial savings in testing expenses over these two methods could accrue to the use of radioisotopes. This excludes expected reductions in shutdown periods not specifically evaluated but of possible importance. Of the three measurements normally required to make acceptance tests of efficiency—pressure head, electrical, and water discharge—the latter is the most difficult, costly, and least accurate.

The new method's advantages of simplicity, low cost, and high precision could encourage routine and more widespread testing. For existing facilities, the availability of additional data of greater accuracy over a wide range of operating conditions and for more than one unit of a multiple-unit installation could prove valuable in refining operating criteria. Better information permitting greater selectivity and control of individual units at a given site, or geographically separated installations, could permit fuller utilization of design machine capabilities and the institution of more timely maintenance programs. Turbines and pumps may thus be made to run closer to top efficiencies so that average efficiency levels attained over a period of time could be somewhat higher.

An analysis was made to determine to what extent the radioisotope method would be applicable to Bureau turbines and pumps constructed and under construction, and the monetary benefits that might be associated with small increases in efficiency of 1 percent or less. Offsets against benefits which would need to be considered are the additional costs of testing and possible incremental costs of repairs to bring the unit back up to design capability. Added repair costs could be minimal as the effect may simply optimize the timing of regular maintenance programs.

The analysis developed value data for selected powerplants and pumping plants covering a range of sizes. Bureau-wide it was found that of the 11,600,000 kilowatts in total powerplant capacity constructed or under construction, 3 million kilowatts were considered amenable to radioisotope flow measurements. Making these machines operate on the average one-half percent closer to their built-in efficiency potentials could yield capacity and energy valued at $250,000 annually, which would have a present worth of over $2 million for 10 years.

For pumping plants, reduced costs of the radioisotope method may permit beneficial application to installations as small as 5,000 horsepower; normally, field testing is economically practicable for only much larger sizes. Of the total 1,700,000 horsepower constructed or under construction, radioisotope flow tests may be applicable to over 1 million horsepower. The potential gain is considered greater for pumps because of greater difficulties in testing. Thus, an average annual yield of 1 percent more of machine efficiency for the 1 million horsepower in pumps could result in a saving in pumping energy worth $150,000, which would have a present worth of $1,300,000 for 10 years .

The successful development of a waterflow measurement method which is highly reliable and has a probable inaccuracy of ± 0.75 percent could have beneficial effects on the industry producing turbines and pumps. Stricter standards that are enforceable could result in elevating levels of machine efficiency specified and ultimately obtained. Under ideal conditions, accuracy of existing methods is considered relatively high; nevertheless, because true rates of flow are not known and field conditions vary, there are questions concerning accuracy of particular tests and whether some methods test consistently higher or lower than others. Penalty clauses now included in invitations to bid provide good examples of the value of fractional efficiency losses in the event the manufacturer fails to meet specified standards. Value curves developed for a wide range of plant sizes demonstrate the economic importance of increases in efficiency of one-fourth, one-half, and 1 percent. The resulting benefits from gains in efficiency are sensitive to installed capacity as it requires a full 1-percent increase of efficiency and a minimum of about 5,000 kilowatts in a turbine and about 4,000 horsepower in a pump to produce an annual benefit of some $1,000. At the other end of the scale, only a ½-percent increase in efficiency for a 1 million kilowatt turbine or 750,000-horsepower pump could be worth $100,000 during the first full year of operation.

Limitations of the radioisotope method involve problems of achieving complete mixing of the solution in a relatively short distance and potential health hazards and public acceptance. The first has restricted the number of installations subject to measurement and means that a more costly multiple-point injection system may need to be used where less than 100 diameters in length of pipe is available. The second limitation is nontechnical, involving following proper safeguards and public education.

Introduction

In the Water-Resource-Conscious World of today, making the best use of limited supplies is a challenge of high order. The ability to accurately measure waterflow is obviously vital to this process. Hydraulic flow must be precisely known before the highest level of efficiency can be demanded from machines transforming the work potential of falling water into mechanical and electrical energy or, the reverse, from energy-consuming machines which lift water to where it can be beneficially used. The vexing problems of making exact measurements have a long history—for it was over 300 years ago that Galileo marveled that his discoveries on the movements of astonishingly distant heavenly bodies met with less difficulty than investigating flowing water before his very eyes. Though much progress has since been made, there is still a continuing and growing need for a simple, cheap, and accurate way to gage large waterflows. This is especially true in attempts to measure discharges in closed conduits under pressure to determine whether turbines and pumps are delivering the kind of performance for which they were designed or which is possible under current technology.

The purpose of this report is to provide insight on the possible economic gains resulting from a measurement method utilizing radioactive tracers. Active research in this field is well underway in the Bureau of Reclamation's Engineering and Research Center at Denver with the expressed objective of developing a rapid, accurate, and inexpensive method of using radioisotopes to measure the rate of flow of water through high-pressure hydroelectric generating facilities and pump systems. The program is being conducted and financed in cooperation with the Atomic Energy Commission as a part of the United States worldwide program to harness the atom for peaceful and constructive uses.

This study is based upon the potential application of radioisotopes to the Bureau of Reclamation's program of building and operating multiple-purpose water development projects. The size and number of turbines and pumps included in that program are illustrated by the 58 hydroelectric powerplants constructed and under construction having a total capacity of 11.6 million kilowatts, and the 96 major pumping plants over 1,000 horsepower having a total capacity of 1.7 million horsepower. Power revenues from operations in fiscal year 1966 amounted to over $100 million. Possible gains from an improved flow measurement method are, of course, not limited to the Bureau's program. From a demonstration of potential usefulness at that program level, however, it would naturally follow that a multiplica-

329-308 O—69——2

tion of the effects would stem from a broader application encompassing other Federal facilities, State and municipal works, privately owned features, and finally water resource developments of other countries.

This study will first survey the various alternative methods available for water discharge measurements in high-pressure conduits, with emphasis placed on Bureau practices. The second section describes the radioisotope approach and specific goals, including a projection of field application procedures and hardware requirements. A cost analysis follows comparing relative magnitude of expenses involved in acceptance tests for turbines and pumps to determine machine efficiency levels. Possible benefits on Bureau-operating projects from the widespread and frequent use of radioisotopes are then generalized. And finally, potential gains from application to new facilities are considered.

Alternative Methods of Discharge Measurements

ACCURATE MEASUREMENTS of flow through hydraulic machinery are essential in design and construction and, finally, in actual operations. Together with measurements of pressure head and electrical output or input—depending upon whether it is a turbine or pump—the basis for testing machine efficiency is thus established. It is universally agreed that the accurate measurement of waterflow is the most difficult and complex aspect of this rating process. The finding of efficiency is of vital interest to both purchaser and seller as it determines not only whether technical guarantees have been met, but has industrywide ramifications on the quality of machines produced. In Bureau projects, provisions are made for the assessment of stiff financial penalties against contractors for failure to meet efficiency specifications as effects may extend over the lives of the hydro facilities normally designed for at least 100 years and which must show financial feasibility in 50 years. Most of the efficiency tests for Bureau facilities are conducted as a part of formal acceptance tests after the completion of installation.

The universal interest in testing-machine efficiency resulted in international codification of procedures and methods. It appears most recently in published form as the "International Code for the Field Acceptance Tests of Hydraulic Turbines," 1963, by the International Electrotechnical Commission and recommended for publication by 19 participating countries including the United States and the Union of Soviet Socialist Republics. In establishing standards for efficiency tests, methods identified in that publication which are pertinent to the problem of accurate flow measurements in high-pressure conduits are (1) pressure-time (Gibson), (2) salt-velocity, (3) dilution, (4) current meter, and (5) pitot tube. The use of radioisotopes as presently conceived fits under the third category, the dilution method.

A choice of the method selected depends upon the particular installation—physical arrangements of intake works, penstocks, manifolds, and turbines differ and can present difficulties in test equipment location and installation. Heads can vary over 1,000 feet, discharges over 3,000 cubic feet per second, and pressure conduits 20 feet or more in diameter. In Bureau acceptance tests, preference is given to the pressure-time (Gibson) method for determining waterflows through turbines. The salt-velocity method is used for turbines where there may be a question of validity of results from the Gibson approach and almost exclusively on pumps since the Gibson test is not applicable to pumps. Brief descriptions of the various methods available for use in acceptance tests are presented in the following paragraphs.

Pressure-time (Gibson) Method.—This method, patented by Mr. N. R. Gibson, was devised to measure flows through a closed conduit or penstock controlled by a valve, turbine, or regulating device located at the downstream end. Pressure variations are measured between two pressure taps located along a pipe section preferably 25 feet or more in length. The variations are determined over a measured period of time during which the valve or regulating device is closed. Changes in pressure are automatically recorded on the chart of a recording device such as the Gibson apparatus, which photographs on a revolving film drum the movement caused by the pressure change of the top surface of a column of mercury in a U-tube manometer. Equipment requirements are modest, do not require installation inside the pipe, and the recording apparatus can conveniently be carried by one man. Use of the Gibson method requires specially trained personnel and in Bureau projects is now accomplished on an outside contract basis. Since the recent expiration of the patent, development work is in progress to improve the recording of pressure-time diagrams.

Salt-Velocity Method.—The salt-velocity method developed by Prof. C. M. Allen and Mr. E. A. Taylor is based on the fact that salt in solution increases the electrical conductivity of water and that a "slug" of brine flowing through a conduit travels at the same velocity as the water and does not lose its identity. A quantity of salt solution is forced into the stream under pressure through quick-acting pop valves. After mixing in the stream, usually with the assistance of a turbulator located inside the pipe immediately below the point of introduction, two or more sets of electrodes located downstream detect the passage of the slug of brine. The average flow velocity is calculated by measuring the speed of the solution as it moves between the electrodes in the pipe section whose interior dimensions and characteristics have been carefully determined. The Code specifies that the first set of electrodes should be at least four diameters from the injection valves and the second set of electrodes at least the same distance downstream from the first set. The equipment is relatively large and complex; the injection facilities used by the Bureau, for example, weigh over a ton. The requirements for internal placement of the multiple-injection valves, turbulator, and electrode detectors make this method expensive. Bureau personnel and equipment are used for project tests.

Dilution Method.—This method consists of introducing a known concentrated solution of a tracer at a steady measured rate into the main flow of water. The tracer may be a solution of salt or dye. Through chemical or fluorescence analysis the concentration of the flowing water with the added chemical is measured at a point far enough downstream to insure thorough mixing. No internal measurements of the pipe are required, nor is it necessary to know the exact distance traveled. The total flow is measured directly by identifying the amount of flowing water "tagged" by the tracer. Only small amounts of dye are required. Presently available instruments cannot measure solution concentrations to a high degree of accuracy.

Primary disadvantages of the dilution method are achieving complete mixing, the requirement for long lengths of pipe, and obtaining precise measurements of tracer concentration in the diluted downstream flows. Recent work in this field has revealed indications of dye concentration decreases due possibly to chemical reaction with elements in the flowing water. The advantages are that simple injection and detecting facilities may be utilized and that no internal pipe measurements are necessary. The application of radioisotopes falls under the dilution method, but greater accuracy is anticipated as the radioactive tracers can be more easily detected and counted.

Pitot Tubes.—This method involves making observations of velocity heads through the use of a tube having a short right-angled bend placed vertically in the flow with the bent part or sensing end pointed in the direction of the flow. Average velocity is determined by measuring a sufficient number of points in a known cross-sectional area of the conduit. The average velocity multiplied by the cross-section area determines the discharge. Reinforced pitometers have been successfully used in pipes up to 5 feet in diameter with flow velocities of 5 to 20 feet per second. By probing from access points on both sides of the pipe, flows in even larger pipes can be measured. The principal disadvantages are that it is time consuming and relatively large forces push on the tube when flow velocities are high, making it difficult to position and secure the instrument. The resulting instability causes inaccuracies. Pitot tube openings are usually small so that sediment and trash can plug the tubes. Flows must be steady for a sustained period to insure proper readings.

Current Meters.—In this method a number of individual current meters are properly placed in open or closed conduits to register individual water velocities. The meters must be accurately mounted and arranged with their axis parallel to the conduit in order to measure the velocity distribution through a cross section in a manner similar to the pitot tube. Several configurations of propeller-type meters are available but their initial cost plus the costs of placement calibration, maintenance, and data analysis make this method relatively expensive. Accessibility for installation of the meters and anchorage assemblies is also a problem. The current meter method is used in Europe, but has not been extensively adopted in the United States.

Accuracy of Flow Measurements in Determining Efficiencies.—The accuracy of flow measurements of the various methods can be high under ideal conditions employing trained personnel and using properly selected, installed, and maintained equipment. The International Code for Field Acceptance Tests presents as a guide the following ratings of probable inaccuracies in the determination of flow.

Method:	*Probable inaccuracy*
Pressure-time (Gibson)	±1.0 percent.
Salt-velocity	±1.0 percent.
Dilution in penstocks	±1.5 percent.
Pitot tube	±1.5 percent.
Current meter	±1.5 percent.

To identify overall probable inaccuracies in testing machine efficiency, the possible errors in measurements of pressure head and electrical output must also be considered. Normally these two measurements are not considered difficult and result in probable inaccuracies of ±1 percent or less. When all factors are combined the overall determination of efficiency is considered subject to a probable inaccuracy of ±2 percent or more depending upon the method and success of the waterflow measurement.

There are differences in opinion among scientists on which of the flow measurement methods performs best and is most accurate. Considering physical variations of installations, no doubt all methods will continue to enjoy some degree of use. As true rates of waterflow under field conditions are not actually known, it would appear that more widespread comparative field testing would prove enlightening. Though limited in amount, information available from comparative studies indicates variations among and within the various methods employed. A classic example is the Finlarig comparative tests [1] where it was concluded that each flow measurement method tested was obviously consistent and gave clearly defined smooth curves; however, even when carefully carried out various methods can give differences of several percent. Also, that it would be unwise to draw general conclusions as to which methods are likely to read high or low until similar comparative tests are made for many different installations under controlled conditions.

The development of a simple and inexpensive method, permitting repeated and widespread testing with a minimum of disruption of operations, could provide a ready means for evaluating performance. Basic accuracy is, of course, dependent upon the degree of inherent error in the measuring system; however, the ease with which a suitable number of samples over a wide range of conditions may be obtained with the radioisotope method could reduce the statistical error among the number of observations. The degree of precision to which modern scintillometers have been developed may substantially enhance the basic accuracy of the measured data. The development of an improved method would provide a tool not only useful in itself but also as a check on the performance of other approaches. The application of radioisotopes holds promise in this regard.

A passing notation is made of a different approach to testing efficiency used in some European countries which is referred to as the thermodynamic method which, incidentally, was also tested in the Finlarig study. It is considered to be

[1] Hutton, S. P., and G. B. Murdock, "Comparative Flow-Measurement Tests at Finlarig Power Station," pts. 1 and 2, *Water Power*, October, November 1962.

particularly suited to heads of about 500 feet or more. Determinations of efficiency are made directly by measuring temperature differentials of flows through the turbine. Hydraulic losses have the effect of slightly raising the temperature of the fluid. Pressure and temperature measurements combined with the knowledge of certain thermodynamic properties of the liquid enable the direct determination of hydraulic efficiency. The mechanical losses must also be evaluated. Probable inaccuracies are considered comparable to the more accurate procedures discussed previously.

The Radioisotope Method

As Mentioned Before, the utilization of radioactive tracers for the purposes of waterflow measurement is a variation of the dilution method. Instead of the conventional uses of salt or dye, the degree of dilution is obtained by counting the gamma (or beta) ray emission of radioisotopes with Geiger counters or scintillation counters. This application of nuclear technology should add greater precision to the dilution approach because of the presence of highly detectable tracer materials, even though very small quantities are employed. As shown in Figure 1, the injection and sampling system now under development would add simplicity and economy to water-measurement techniques.

Three different approaches to the measurement

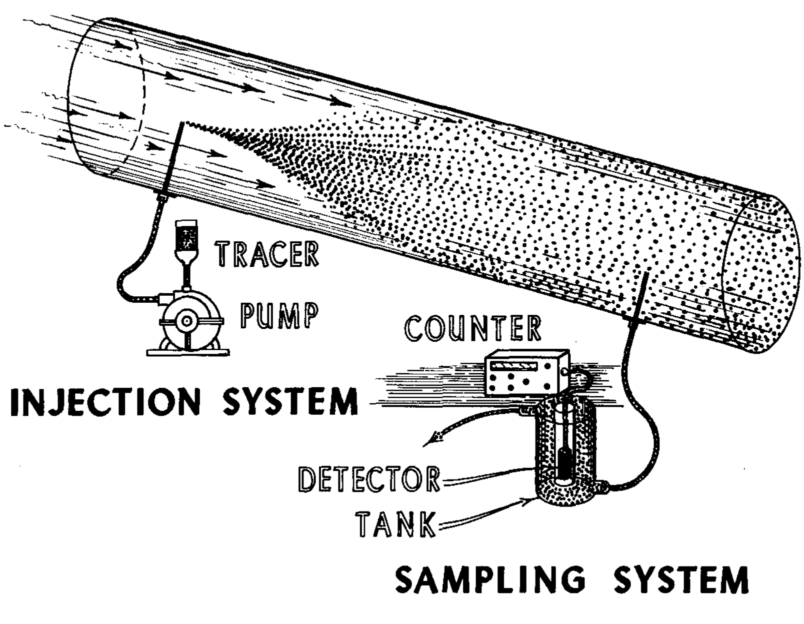


Figure 1.—*Radioisotope method for measuring high-head flows.*

of radioisotope concentrations offer opportunities for improvements in accuracy. These are the conventional dilution approach, the total count method, and the integrated sample method. In the first, a radioisotope solution of a known concentration is injected at a steady rate and the concentration is counted downstream. Unlike the dilution approach where the absolute quantity injected need not be known, the total count method requires that the radioactivity be completely quantified since the solution is injected as a pulse. A downstream detector and recorder sums up the radioisotope emissions during the passage of the pulse. The integrated sample method is a variation of the total count approach where individual samples are continuously withdrawn from the flow for a period starting shortly before injection and continuing for a short time after the tracer has passed the point of sampling.

As with other materials used in the dilution approach, achieving complete and thorough mixing of the radioactive material is a critical factor in the outcome of the measurements. The distance required between the points of injection and measurement can determine the type of injection equipment required and whether it is feasible to attempt an application of radioisotopes. Where adequate mixing can be assured, the radioisotope method should work equally well on turbines and pumps. By taking advantage of the turbulence produced by passage through pumps, some opportunities are present for accelerating the mixing process.

Hardware Requirements.—The amount of radioisotope solution needed for a particular test is small (1–10 liters) so that the injection equipment can be relatively simple and compact. Depending on the method used in detection, two types of injection systems are used. One is for application at a constant measured rate and the other for pulse injection of a measured quantity rapidly under high pressure. The feed pump for constant rate injection would weigh about 80 pounds and would be capable of producing a steady discharge (milliliters per hour) at pressures up to 5,000 p.s.i. The pulse injection apparatus would consist of pressure cylinders and valves mounted on a single portable rack and would be charged by compressed air or nitrogen. The total weight of the pulse injection apparatus would approximate 150 pounds and could be installed by one man. Average initial cost for either of these systems would be about $1,000.

The equipment items discussed in the preceding paragraph are pressure generating facilities exterior to the pipe. These would be used in connection with a single-point injection system where the solution is introduced into a tube, about three-fourths inch in diameter, thrust through a watertight seal to the centerline of the flow. Present indications are that single-point injections can be employed at installations where 100 or more pipe diameters in length are available for mixing the tracer in flowing water.

When less than 100 pipe diameters in accessible pipe length is available, a multiple-point injection system will more likely be required, which would make introduction of radioisotopes more complex and time consuming. However, simpler techniques such as very high-pressure injection are under study. Although on a smaller scale because of the relatively smaller amount of solution required, a multiple-injection system for radioisotopes would be quite comparable to the corresponding salt-velocity system. Provision must be made for initial dispersion of the tracer at a number of discharge points through the cross section of the pipe. Although initial costs are greater, the important disadvantages of the multiple-point injections are the requirements for installation inside the pipe and the possible disruption in operations. The relative costs of the single- and multiple-injection systems are analyzed in the next section.

Counting and recording instruments must be highly accurate and reliable for precision measurement of radioactive concentrations. Investigations disclose that these instruments should be 60-cycle, line-operated because portable battery-operated sources of power are subject to irregular performance. A list of counting and recording instruments would include a high- and low-voltage power supply source, electronic scaler, analog recorder, digital printout, and radiation detector. Initial cost of these facilities, all presently available, would be about $10,000 and with proper care should have a service life of some 10 years. The instruments are relatively small and compact and can be easily transported and installed at the field site by one man.

Accuracy.—One of the goals of the research program on the use of radioisotopes is to improve the precision of waterflow measurements in addition to the objectives of quick and simple application at low cost. Under ideal conditions, probable inaccuracies of the best methods now being used are indicated to be ±1 percent. Development of the radioisotope method is directed toward achieving a probable inaccuracy of ±¾ of 1 percent. As discussed later, small percentage gains in accuracy in the field of hydraulic flow measurement may result in important financial and economic benefits.

Limitations.—Two important limitations to radioisotope application are accomplishing complete mixing of the radioactive solutions in the pipeline and licensing requirements because of possible health hazards in handling and the release of radioactivity to the environment.

The problems of mixing the tracer in the pipe flow can limit applicability and increase the complexity of the facilities required. The breakover point in mixing distance required is anticipated to be 100 diameters in pipe length. More elaborate mixing devices, longer shutdown periods, and increased expense would be required with the shorter distance unless present efforts to develop other techniques are successful. When the length of accessible pipe falls below about 25 diameters it is not expected that the radioisotope method can be successfully applied. (This condition also poses problems for the salt-velocity method.) With regard to pumps, there is the possibility of injecting the tracer materials in the intake which could facilitate mixing from the additional turbulence and reduce the length of pipe required.

A Federal license is required to handle the radioactive material to insure proper radiation shielding while shipping and handling. The release of radioactive solutions to public water supplies requires the formal approval of local, State and, in most cases, Federal authorities. When domestic and municipal uses are involved, some difficulties in securing permission may be encountered. When properly informed of the safeguards undertaken, objections from private or public bodies are expected to be reduced to a minimum. The tracers now being used are Gold-198 with a radioactive half life of 2.7 days and Bromine-82 with a radioactive half life of 1.5 days. The maximum concentration released to the flow would be only a small fraction of the rigid standards controlling the amounts of radioactivity permitted for human consumption. As with other radioactive materials, such as those now directly injected in the human body for medical diagnosis, public acceptance of the use of radioisotopes for waterflow measurement purposes is keyed to the success of educational programs and good public relations practices.

Current Status of Radioisotope Studies.—The last decade has seen an increased use of radioisotopes for flow measurement in both open and closed conduits. Generally, however, flow measurement in pipe has been confined to small-diameter, low-pressure water, oil, and other lines.

Previous studies by the U.S. Geological Survey in cooperation with the Atomic Energy Commission and the Tennessee Valley Authority have shown the radioisotope method promising with large low-head turbines and with a possible inaccuracy of about ±1 percent.[1] Considerable work has been done in the United Kingdom on perfecting radioisotope techniques for measurement in pipe using both dilution- and velocity-type techniques. Recent investigations on flows in small-diameter pipes indicate probable inaccuracies well within ±0.5 percent can be obtained consistently.[2]

The Bureau's study is exploring an area of measurement of very large flows in closed conduits under high heads using the shortest possible length of pipe without sacrificing a high degree of precision and the economy and convenience associated with radioisotope flow determinations. Problems of injection, mixing, and sample collection and measurement are compounded by the large flows and heads. Current field studies at Flatiron Powerplant, Colo., are pointed toward field testing of equipment and procedures, establishing reliability, identifying areas for further improvement, and studying tracer mixing. The results to date are approaching the goal of probable inaccuracy of less than ±0.75 percent. Field tests of the method have proven successful and additional measurements are planned for a pumping unit at the Flatiron Plant in order to gain comparable data on the application to pumps. Laboratory and field studies are continuing in order to further perfect equipment and field procedures, and to further define the limitations of length of pipe imposed by mixing requirements.

---

[1] Frederick, Bernard J., "Measurement of Turbine Discharge With Radioisotopes," USGS Report TEI-855, October 1964.

[2] Clayton, C. G., et al., United Kingdom Atomic Energy Authority, Report No. SM84/39, 1967.

329-308 O—69——3

Cost Analysis

An Important Objective of the radioisotope approach is to achieve simplicity and economy in application. This accomplishment would meet an expressed need and could encourage more frequent testing of turbine or pump capabilities, especially on operating projects. Insofar as new facilities are concerned, the amount of cost involved in water discharge measurements is not as an important factor in determining whether acceptance tests of new facilities will be made, since testing is a prerequisite to contract completion and represents a small fraction of the initial investment required. However, a significant reduction in the cost or complexity of making accurate flow measurements could influence the present practice of testing at random only one machine of a multiple-unit installation. As discussed subsequently, possible minor variations of efficiency among units (a fraction of 1 percent), and identification of optimum operating characteristics peculiar to specific units over a range of heads could justify testing more than one unit if the associated costs, inconveniences, and shutdown time were reduced to a minimum.

An analysis was made to provide the relative order of magnitude of total costs incurred for formal acceptance tests of efficiency and the proportions associated with the more difficult waterflow measurement phase. For comparative purposes, estimates were predicted for the radioisotope method based on best information available assuming a routine application. The two conventional methods selected for comparison are the ones now in predominant use by the Bureau in testing high-head turbines and pumps, the pressure-time (Gibson), and the salt-velocity methods. As indicated previously, where physical conditions permit, the Gibson method is favored for turbines; the salt-velocity method is used for all pumps and for some turbines.

Because each test must be engineered to fit the particular installation involved, the estimated costs shown for the two methods in table 1 must be considered approximate.

It is apparent from the estimates that the major portion—about one-half of the totals—is for measuring discharges with the balance common to all acceptance tests regardless of method used in determining flow. It is noted that all costs of the salt-velocity application are for Bureau labor, materials, and supplies and include minor depreciation expenses on about $5,000 of reusable equipment. In the Gibson estimate, about $6,000 is included for outside contractor fees. Inasmuch as the Gibson patent rights have expired, consideration is being given in the Bureau to develop necessary

TABLE 1.—*Comparison of typical costs of formal acceptance tests for a single turbine-generator unit using the pressure-time and the salt-velocity methods of flow measurement*

Item	Pressure time (Gibson)	Salt velocity
Water discharge measurements	$9,000	$7,700
Pressure head measurements	700	700
Electrical measurements	2,500	2,500
Brochure and report preparation	2,800	2,800
Test supervision	1,600	1,600
Total	16,600	15,300

TABLE 2.—*Predicted costs for radioisotope method for waterflow measurement*

Item	Single-point injection	Multiple-point injection
Labor	$700	$1,100
Transportation and travel expenses	200	200
Radioisotope	300	300
Engineering design and fabrication of fittings and pipe	300	1,500
Depreciation of equipment	300	300
Total	1,800	3,400

equipment to conduct its own pressure-time tests. Hardware requirements are considerably less than those necessary for the salt-velocity method and it is expected that, at some future time, costs for the pressure-time approach can be reduced.

The estimates of the potential costs for the radioisotope method assume that a small cadre of technicians would be trained in handling the required radioactive tracers and the counting and recording instruments. One trained and experienced technician would be available in each region and would secure the necessary field assistance from operating personnel, preferably located at the site. All instrumentation and special equipment would be centralized at one location in the region and be designed for maxium portability and rapid installation. Two estimates were prepared, one reflecting the use of a single-point injection system where the penstock or discharge line has the equivalence of 100 pipe diameters in length accessible for testing and the other requiring multiple-point injection which would have much wider application where as little as 25 pipe diameters in length are available. A summary of significant elements of cost for radioisotope water measurements is presented in table 2; other costs in a formal acceptance test would be the same as previously listed.

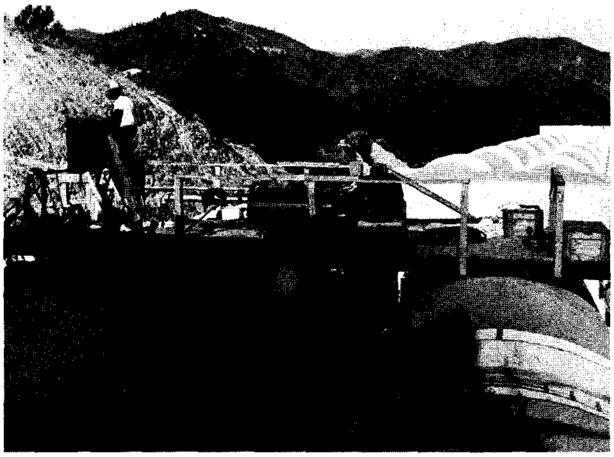
As indicated in the preceding table, the single-point injection routine would require minimum labor and hardware costs. It is expected that a major share of the labor costs will be for local operating personnel, as it is expected that the regional technician would direct and assist installation of equipment on the first day, perform the radioisotope injections and measurements the second day, and reduce the data and remove the equipment on the third day. By use of automatic recording instruments the tests can be conducted with a minimum of time and effort. The multiple-point injection system would require dewatering, design and installation of a more elaborate injection assembly, and consequently additional expense in labor and material.

An important factor bearing on the appraisal of costs not recognized in the preceding estimates is the relative shutdown time required under the various test procedures. This can be a crucial item for turbines and pumps in continuous operation. Interruption of operations is not as important in formal acceptance tests because internal inspection of water passages and vital parts of the machinery is a required procedure.

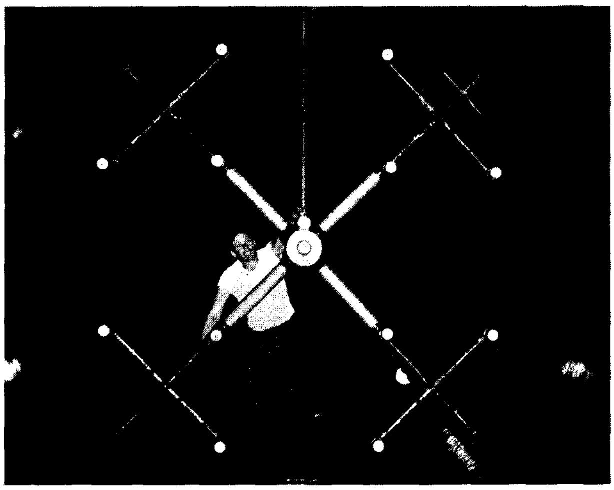
An array of methods according to the length of shutdown period would rate the salt velocity as the most demanding because of its elaborate injection, mixing, and detection devices that must be placed inside the conduit. The pressure-time (Gibson), pitot, and radioisotope methods would require significantly less time. In this regard, a significant advantage would accrue to the single-injection radioisotope procedure, as shutdown can be greatly minimized and possibly altogether eliminated if advance provisions were made for the relatively inexpensive taps and fittings permitting access to the pipe under pressure. Multiple injection of radioisotopes would be more time consuming, but still would require less time than the salt-velocity method.

The photographic comparison presented in figures 2 and 3 provides perspective on the relative size of the facilities required for application of the salt-velocity method and the radioisotope method.

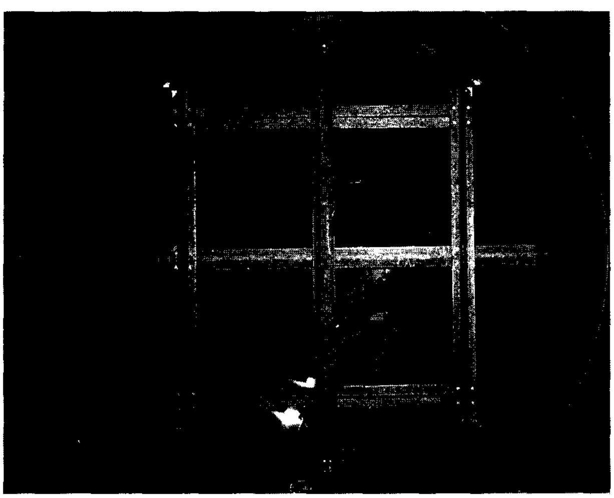
Salt Velocity



Brine injection station.



Turbulator.



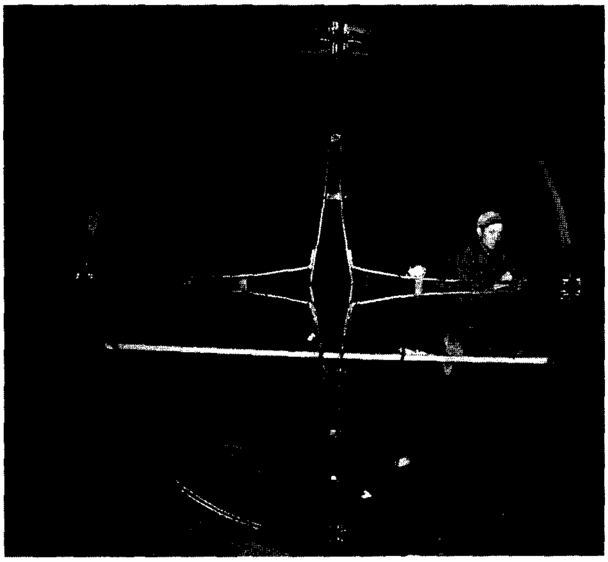
Multiple-point injector.

Radioisotopes

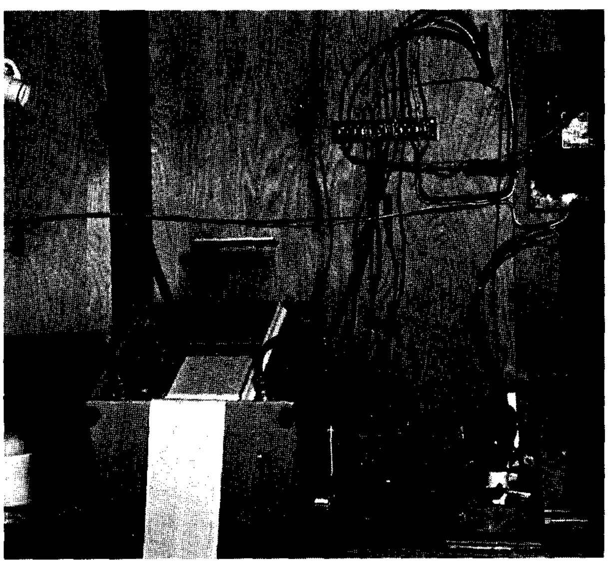
Radioisotope injection station—single-point injector Small volume of radioactive solution (< 1 liter) is pulse injected into the flow using nitrogen or compressed air.

FIGURE 2.—*Comparison of injection equipment for salt-velocity and prospective radioisotope methods.*

Salt Velocity



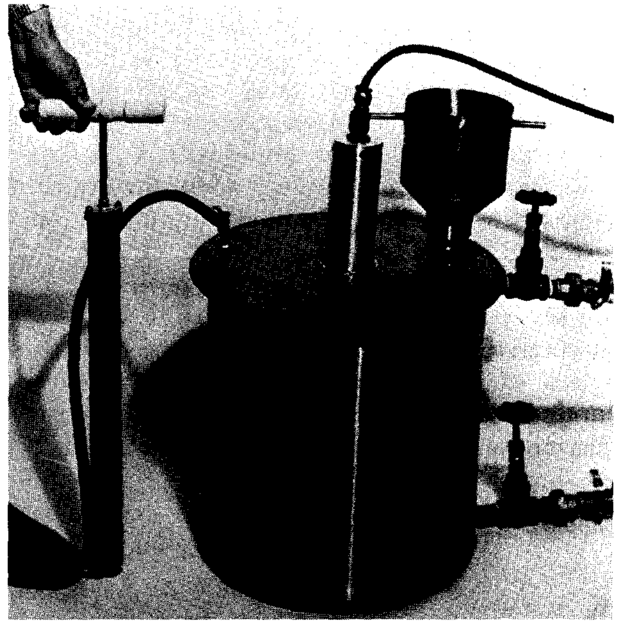
Electrode No. 1 (Two required).



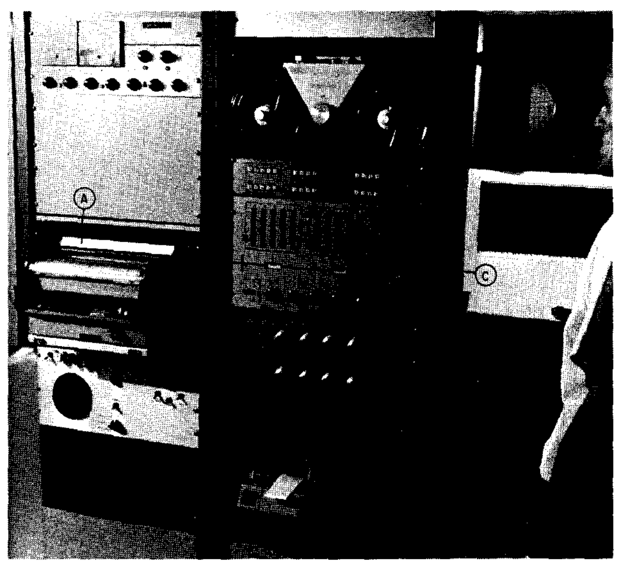
Two-channel direct writing recorder.

FIGURE 3.—*Comparison of detection and recording equipment for salt-velocity and prospective radioisotope methods.*

Radioisotopes



Flow sampling tank and nuclear detector.



Nuclear counting equipment in mobile laboratory—Instruments necessary for flow measurement inside bordered areas (A, B, C).

It is noted that only those instruments necessary for the radioisotope test have been blocked out on the instrument panel of the mobile nuclear laboratory. The especially equipped truck is used for performing field tests using radioisotopes in ground-water studies, open-channel flows, as well as in studies of flows in high-pressure conduits.

Routine checks of efficiency could involve considerably less cost than the totals shown for a complete and formally documented acceptance test. The costs of brochure and report preparation and test supervision shown in table 2 could be reduced substantially and, in those instances where there is a lack of information on efficiency and less accurate data are useful, the expense of the electrical measurements can be materially decreased by using the instruments normally available in recording day-to-day operations. These reductions, together with the possibility of reducing conventional water measurement costs by three-fourths to one-half with a minimum of shutdown time, should make the benefits from accurate flow measurements from using radioisotopes within reach of many operating hydroelectric and pump projects having a wide range of installed capacities. Since the costs appear attractive, the next step is to analyze the possibilities for widespread use from both an economic and physical viewpoint in order to get some insight on potential benefits from radioisotope application to operating and new projects.

Application to Operating Projects

ONE OF THE MOST PROMISING OPPORTUNITIES for use of the radioisotope method of flow measurement lies in the potential widespread application to existing projects. The provision of highly accurate and readily available discharge data on flows in high-pressure conduits over the whole spectrum of operating conditions could result in better utilization of existing machine capabilities. Substantial benefits could result from the use of a new measuring tool not now available by capitalizing on small increases in the overall average efficiencies of turbine generators and pumps operated over a period of time, and from better control of available water supplies.

Powerplants.—Often the only precise information on the performance of a particular turbine-generating unit is the result of the efficiency test made at the time of acceptance on completion of the facility. Inasmuch as acceptance tests are oriented toward determining that warranties have been met, optimum operating criteria are assumed and tests are not scheduled until the design head is reached. (Under some relatively rare circumstances, such as occurred at Glen Canyon Dam, the design head might not occur until after the supplier's guarantee on efficiency has lapsed.) Day-to-day and month-to-month operations over the hydrologic cycle seldom equal the ideal design parameters, and consequently there is a need for accurate performance ratings over a broad range of conditions.

In those projects where efficiency tests have been completed and flowmeters installed and calibrated, performance characteristics can be extrapolated with accuracy within some reasonable margin of the test point. When operating heads depart significantly from the design head, less accurate calculations and approximations on relative efficiency of the turbine generators must be relied upon. Furthermore, many of the older projects do not have the benefit of calibrated flowmeters.

The time lapse between the initial installation, at which time tests are made, and current operations can also adversely affect performance due to wear and tear on the machines. Physical inspection and measurement of wearing parts of the turbine and available flow indicators can indicate possible losses in efficiency, but it is questionable whether reduction of a few percentage points can be detected in this manner. Thus, the timing of repairs necessary for restoration to initial efficiency levels may not be at optimum intervals. An improved and convenient method such as radioisotopes may offer would facilitate inspection.

Using available information, performance curves for powerplants are normally prepared for each installation covering the full range of operating conditions and become the basis for selecting specific units needed to meet certain demands. In many systems, power generation is greatly influenced by water releases for other purposes. Where there is a choice of making the necessary water releases through two or more geographically separated installations or individual units within an installation, the logical selection would, of course, be to utilize the best machine available to get the most kilowatt-hours out of a given quantity of water. On the other hand, when electric energy is the primary purpose for releases of water the most efficient plant—if it can be identified—would be called upon to produce the required power with a minimum of water to avoid unnecessary waste. Power contracts may specify the amounts to be delivered under certain water supply situations, especially during dry periods. In these circumstances, there are distinct advantages in being able to predict turbine performance within a small percentage of error under conditions which may widely differ from those existing at the time acceptance tests were conducted.

The availability of an accurate and inexpensive means to measure flow discharges could permit the institution of a program calling for periodic and routine testing of efficiency so that the performance characteristics of individual turbine generators could be precisely known. Then, not only could greater use be made of the best power units, but also maintenance programs could be more timely scheduled as accurate basic data would be at hand to analyze the tradeoff between the incremental expense of making necessary repairs and adjustments, and potential gains in power revenues. Optimization of maintenance programs could mean an average increase in costs from scheduling repairs at more frequent intervals; on the other hand, it is possible that precise efficiency data may show that economies can be gained by lengthening the interval.

Before estimates of potential benefits can be reduced to dollars and cents, the extent to which the radioisotope can be applied to powerplants in the Bureau's program must first be determined. The current list of 58 powerplants constructed or under construction having a total capacity of 11.6 million kilowatts was screened to make this determination. As mentioned earlier, the length and accessibility of high-pressure penstocks are impor-
that the radioisotope method cannot be expected to
bility. This limitation resulted in the elimination of a number of concrete dams having short penstocks. It is noteworthy that among the larger plants excluded were Hoover and the Grand Coulee developments, as current research efforts suggest that the radioisotope method cannot be expected to perform with accuracy for these projects.

A total of 21 powerplants having a combined installed capacity of 3 million kilowatts was delineated as having a reasonable chance for successful application of radioactive tracers. A further inspection disclosed the relative influence of the penstock length requirement of 100 diameters by identifying those plants susceptible to the use of the simple and less costly single-injection system. Although it was found that only one-third of the installed capacity subject to radioisotope application fell in this preferred category, two-thirds of the total number of plants were covered. This finding has its favorable side as a large number of the smaller units were included which could better afford the less expensive single-injection approach. The category requiring the more expensive and complex multiple-injection assemblies encompassed larger plants such as Glen Canyon, Shasta, Yellowtail, and Hungry Horse which, of course, could more readily absorb the greater expense involved but might still be disadvantaged due to shutdown requirements.

Several value curves were developed to test the hypothesis that a small fraction of an increase in efficiencies for turbine generators can produce substantial economic benefits. Since large Federal investments have already been committed, any incremental cost would be restricted to additional testing, modifications of machines over and above that now incurred, or refinements in operating techniques. It is noted that an increase of 1 percent in the rated efficiency of a turbine means more than a 1 percent gain in the overall effect on power production (or consumption in terms of a pump). For example, a gain of rated efficiency from 90 to 91 percent means an overall gain in productivity of one-ninetieth, which equals 1.11 percent. The value determinations in this report reflect the overall effect on electric power production (or consumption in the case of pumps).

As presented in figure 4, separate curves were computed for possible increases in machine efficiencies of one-fourth and one-half percent covering the 3 million kilowatts in the Bureau's program subject to the radioisotope flow measurement method. The amounts shown on the left scale are values at the time improvements are first made reflecting "present worth" using the current Federal interest rate for water resource developments of 3¼ percent. The bottom scale indicates the number of years benefits might accrue. Thus, from the curves it can be readily determined how much one is willing to pay today for increased machine efficiency that would last a specific period of time; for example, a one-half percent increase in overall efficiency lasting 10 years would have a present value of $2.2 million. For the first year at the same increase in efficiency the value would be about one-fourth of a million dollars.

These values are based on generalized assumptions regarding plant factor and power rates per kilowatt-hour. These factors would actually vary among major river basins as well as individual projects. The use of rates representing power revenues introduces some conservatism in the study for, in many instances, the rates are below average market prices. If potential benefits were measured in terms of alternative costs at other than Federal financing in accordance with present evaluation procedures, values would tend to be higher. It is believed that the averages used which reflect a 50-percent plant factor and a 4-mill-per-kilowatt-

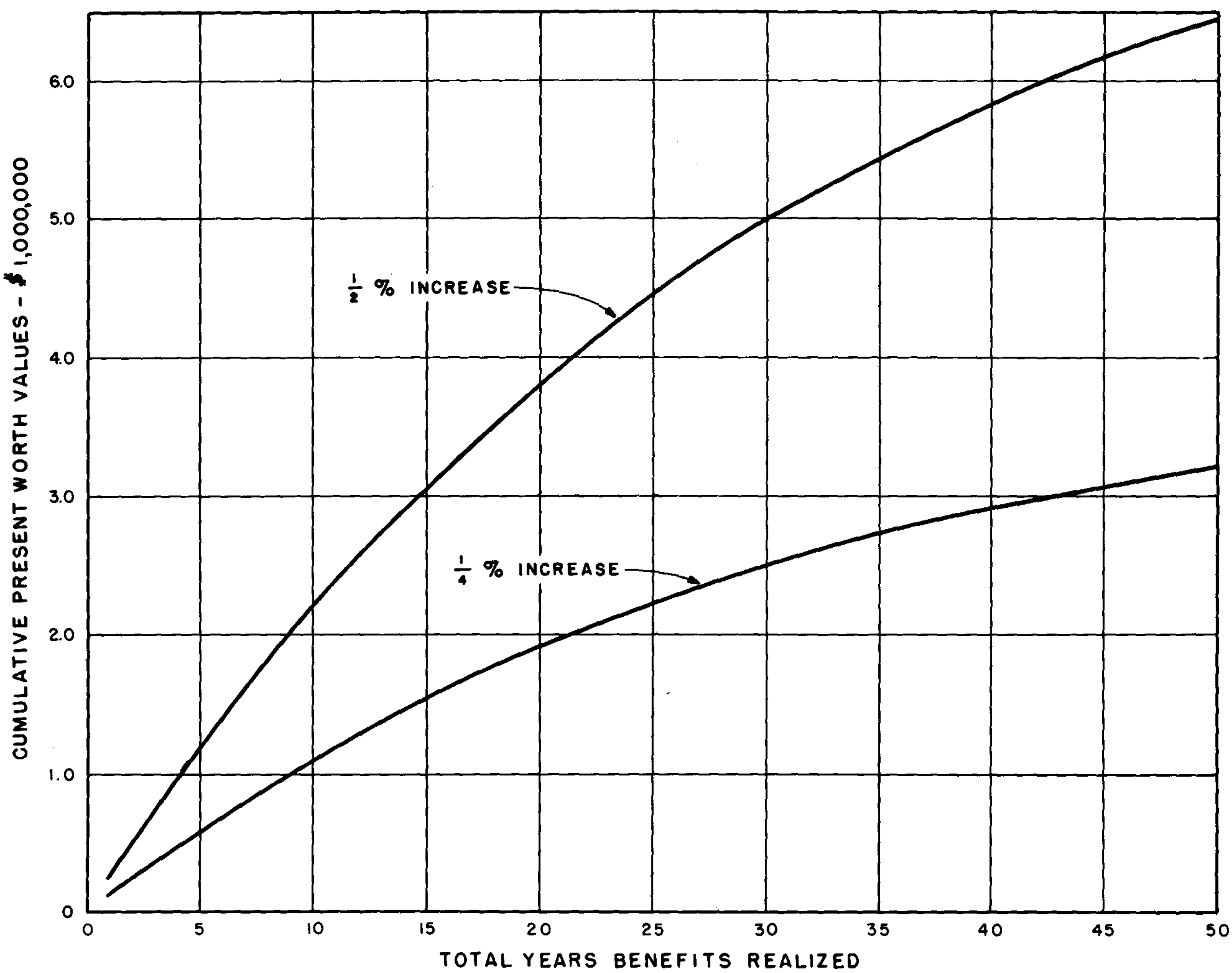


FIGURE 4.—*Potential benefits from fractional increases in machine efficiencies from 3 million kilowatts of installed powerplants considered subject to radioisotope waterflow measurements.*

hour rate are reasonable. The relationships, however, are linear and adjustments up or down for either plant factor or rate can be easily approximated. It is noted that reductions in plant factor are normally attended with an increase in the value of energy per kilowatt-hour because of use as peaking.

Appraisals were also made of the potential gains from individual plants with the evaluation criteria tailored to meet the particular project. Each powerplant is operated as part of basinwide systems; consequently, average conditions within each basin were postulated. The value of power as reflected in power revenues can vary significantly from the Pacific Northwest where firm power rates at comparable load factors may yield 4 mills or less as compared to up to 6 mills in the Colorado River storage project. Missouri River Basin project and Central Valley project fall in between these points. Sales of nonfirm, secondary, and pumping energy have the effect of reducing the average returns.

The following tabulation illustrates the potential economic gains for selected projects having a wide range of installed capacities, and assuming 1 percent increase in efficiency. It was considered that an increase of 1 percent was possible on an individual plant basis, but that the fractional increases previously presented were more appropriate as an overall average gain covering all powerplants susceptible to radioisotope flow measurements. The smallest installation shown is for one unit of the Flatiron Powerplant of the Colorado-Big Thompson project to provide an idea of the relative magnitude of gain for smaller units. Values for still smaller units can be approximated on a straight proportionate basis. Potential gains presented for selected years are cumulative and reflect present worth at the current interest rate of 3¼ percent.

Pumping Plants.—The general approach in determining potential benefits from the operation of high-pressure pumps closer to maximum capabilities through better discharge measurements is similar to that used to evaluate powerplants. Frequent availability of good information on relative efficiences would provide greater discretion in selecting the best units for baseload operations, more timely maintenance programs so that year-to-year outputs consistently score higher on the efficiency curve, and better control and regulation of water supplies. The most obvious gains would be potential savings in pumping energy.

An analysis of the application of the radioisotope method to pumps pointed up two important variations from conditions encountered when considering powerplants. First, it was noted that there was a preponderance of relatively small pumps and consequently a greater sensitivity to the expense of testing; and, secondly, there was a greater potential in realizing several percentage points in efficiency because of a general lack in testing and the greater incidence of wear-inducing sediment in water pumped.

In Bureau operations, formal acceptance testing in the field has been limited only to the larger pumps with the salt-velocity method being used almost exclusively. In the recent past, five actual tests have been conducted at project sites. Shop tests normally form the basis for acceptance for smaller plants (up to 2,500 horsepower). The expense; the requirements of access to discharge lines for internal placement of the elaborate injection, mixing, and detecting equipment; and the shutdown requirements all combine to limit the number of tests run using the salt-velocity method.

Flow measurements by use of pitot tubes may prove to be an attractive alternative method for application to small installations; however, technical

TABLE 3.—*Present worth of potential gains from a 1-percent increase in turbine-generator efficiency for selected plants*

Powerplant	Region	Capacity (megawatts)	Possible increase in values—in thousands of dollars				
			1 year	5 years	10 years	25 years	50 years
Glen Canyon	4	900. 0	210	990	1, 820	3, 670	5, 320
Hungry Horse	1	285. 0	23	110	200	400	580
Yellowtail	6	250. 0	34	160	290	580	850
Trinity	2	100. 0	19	90	170	330	480
Flatiron No. 1	7	31. 5	6	30	55	110	160

problems of obtaining precise results as yet have not been overcome. At present that method has occasional field use, primarily in connection with comparative studies in problem areas where several methods are employed.

In appraising the extent of radioisotope applicability, the current list of Bureau pumping plants, 1,000 horsepower or larger, either constructed or under construction was examined. In the screening process it became apparent that physical criteria had to be supplemented by economic considerations because potential gains from a 1,000-horsepower installation would justify only a small additional dollar expenditure. As a result, a minimum plant size of 5,000 horsepower was selected as the break-even point where potential gains from a small increase in machine efficiency approximated the anticipated cost of a flow test using radioisotopes. The smaller plants have two factors which tend to offset size: one is that there should be a greater opportunity to pick up several percentage points in efficiency; and two, the average cost for energy is higher as often local sources of power must be relied upon.

It is recognized that a pump installation normally consists of a number of individual units, each of which could have a separate discharge line requiring individual testing. It is expected, however, that the added costs of testing more than one unit at the same site and time would be small, especially where several units manifold into a single discharge line necessitating only one setup and where the single injection of radioisotope material is permissible.

Inspection of published statistical data as of 1966 disclosed that of the total rated horsepower of 1.7 million in 96 pumping plants, 1.3 million horsepower in 13 plants met the physical and economic conditions of applicability for radioisotope testing. The importance of large units was conspicuous by the fact that four of the 13 plants ranged in size from 135,000 to 460,000 horsepower, and nine plants were in the 5,000- to 14,000-horsepower range. All but two of the plants were considered amenable to the application of the less expensive single-injection system. These two plants were over 200,000 horsepower in size and could well afford the extra cost. As mentioned previously, due to the possibility that the pump impellers can be used as mixers for the radioisotope solution, the single-injection system could have an even more widespread application.

Economic indicators were developed on relative magnitude of values resulting from possible reductions in energy requirements for the 1,300,000 horsepower susceptible to radioisotope water measurement techniques. A value curve representing 1-percent potential increase in efficiency was plotted using power values comparable to those assumed for powerplants. Federal pumping power rates were not used in computing the monetary benefits as these are considered to be artificially low. This is due to the large influence of low, partially subsidized irrigation pump rates which result from present policy and legislative history to encourage irrigation. Furthermore, any power released by reduced pumping should find a ready commercial market.

As with powerplants, variations in power values and plant factors occur from one regional area to another and require generalizing and weighting in the selection of averages used. Precise and detailed statistical analyses are not considered necessary for the purposes of this study as the emphasis is to develop value indicators and trends. However, some mention of the wide variations encountered in plant factors and power values may be of interest. The lowest plant factor was under 15 percent and represented the pumping cycle of a reversible pump-turbine facility. Pumping only during irrigation seasons produced factors of about 30 percent depending upon climatological conditions; year-round pumping for regulation or supplying municipal and industrial needs increased annual operations to up to 90 percent of the time. The capability to avoid pumping during daily or seasonal electrical peaking hours and location in areas of "cheap" power resulted in values as low as 3 mills. On the other hand, where pump operations are located in areas of higher electrical fuel costs or where local sources must be relied upon, power would have almost twice that value—one was as high as 7½ mills.

Figure 5 presents a value curve showing the potential benefits from improving operations on 1.3 million horsepower in pumps subject to radioisotope measurements. The curve assumes a power value of 4½ mills and a plant factor of 40 percent, which represent averages from weighting the most significant factors. By operating 1 per-

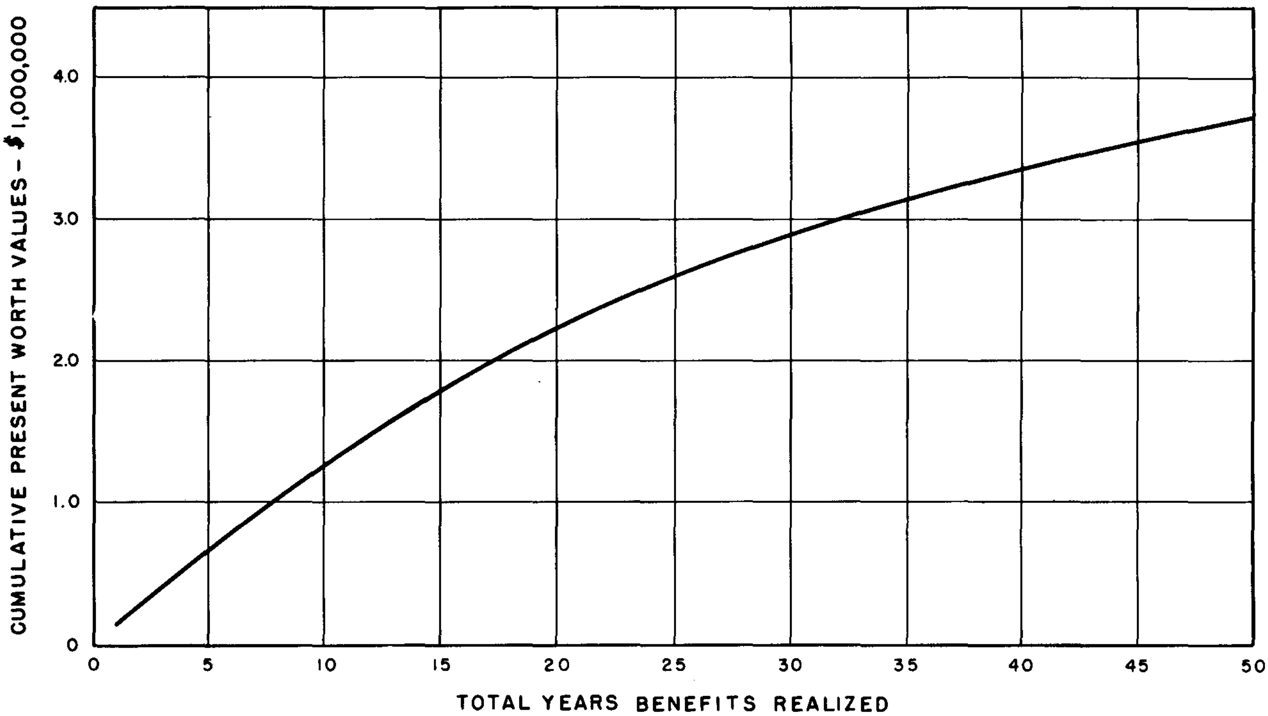


FIGURE 5.—*Potential benefits from 1-percent increase in machine efficiencies from 1,300,000 horsepower of installed pumps considered subject to radioisotope waterflow measurements.*

cent closer to actual machine capabilities, benefits realized could amount to $150,000 for the first year and accumulate to almost $1,300,000 in 10 years. The largest installation included is the San Luis pumping plant, rated at 504,000 horsepower. All San Luis units are reversible and have a total generating capability of 424,000 kilowatts. This pump-generator plant, as well as one other, is included in both the powerplant and pumping plant studies as separate waterflow measurements are necessary for testing efficiencies in each of the pumping and generating cycles.

The possible variations in evaluating criteria for efficiency gains strongly indicate that case-by-case analyses would need to be made to determine, first, the degree of testing expenses involved and secondly, in the event that repairs are necessary just how much added cost will be incurred. As discussed previously, the effect on costs of repair would more than likely be in changes in the timing of maintenance programs. To provide some illumination on the amount of added cost a 1-percent average increase in efficiency could support, selected plants were studied individually and the results are summarized in the next table. The apparent poor correlation in size and benefits is due to the wide variations in plant factors and values of electric energy.

TABLE 4.—*Present worth of potential gains from a 1-percent increase in pump efficiency for selected plants*

Plant	Region	Capacity (horsepower)	Possible increase in value—in thousands of dollars				
			1 year	5 years	10 years	25 years	50 years
Grand Coulee	1	390, 000	30. 0	140	260	520	750
Tracy	2	135, 000	39. 0	180	340	670	980
Flatiron [1]	7	13, 000	1. 3	6	11	22	32
Canadian River pump No. 2	5	5, 000	1. 9	9	17	34	49

[1] Pump-generator used primarily as pump.

Water Control.—It naturally follows that the ability to accurately measure discharges through high-pressure turbines and pumps not only produces benefits in terms of energy gained or saved but also advantages in the management of water supplies. Releases through powerplants are normally into open river channels and are difficult to gage precisely. The ability to calculate flows within a small margin of the true flows would mean better administration of water rights and improved accounting of supplies released to various water users. This would make a contribution toward the elimination of waste and may mean greater availability for project use.

Pump discharges into open channels are difficult to measure within a percentage or two of actual flows. Through a periodic determination of efficiencies, pumps can be maintained to operate closer to their designed capabilities so that full output can be relied upon during those critical dry periods when maximum capacities are taxed. Timely water applications can make substantial differences in irrigated crop yields. Water put to municipal and industrial (M. & I.) use can have even a higher value. Greater amounts of M. & I. supplies are expected to be delivered through high-head pumps over longer distances. In view of project repayment requirements and equitable distribution of supplies, accurate metering of M. & I. water is to the best interest of all parties involved.

A number of variables are involved in reducing the benefits from improved water management to a hard dollar estimate. There are many links in the chain, beginning from the storage and diversion of riverflows to the final delivery to the water user. Water losses in the form of evaporation, transportation, and on-farm application all play major roles in the control and distribution of water. Nevertheless, the provision of an accurate measuring tool such as that anticipated by the use of radioisotopes in high-pressure conduits can make a contribution to better management and use of valuable water supplies.

Application to New Facilities

PRECEDING SECTIONS indicated that the radioisotope method for determining hydraulic flow in high-pressure conduits has potential application to a significant percentage of projects constructed or under construction by the Bureau. The availability of a highly precise method which can measure discharges from turbines and pumps within an expected probable inaccuracy of $\pm 3/4$ of 1 percent could encourage the production of more efficient machines for inclusion in future projects. It is generally agreed that in any industry where it is difficult to establish rigid specifications or standards and which lack a precise gage for checking acceptability within these criteria, there may be opportunities for product improvement not yet exploited. A method which can accurately determine whether design standards are met and which is agreeable to both the seller and the buyer can encourage competition and result in the upgrading of the product. A highly accurate method for measuring discharges through turbines and pumps—an expressed goal of the radioisotope research program—could make some contribution to expectations of securing machinery having small but economically significant gains in efficiency.

An indication of the value of a fraction of a percent of machine efficiency is provided by a review of standard penalty clauses included in invitations to bid. Provisions for financial adjustments are thus made in the event that the supplier fails to meet the warranted efficiencies operating under the specified design conditions. Several examples are provided for various sizes of powerplants and pumping plants. As noted in the following summary table, the amount of penalty is a direct function of the size, percentage of time the plant is expected to operate, and power values. Penalties are usually shown separately for losses in energy and capacity and are specified to the nearest one one-hundredth of 1 percent. For purposes of presentation, the penalties have been converted to the equivalence of a 1-percent loss.

The possibility for realizing benefits from increased efficiencies in new powerplants is perhaps not as great as those for pumping installations. A good many of the best hydroelectric damsites have been developed and a large share of those remaining represents large concrete structures with relatively short penstocks and consequently are not good prospects for the use of radioisotopes. On the other hand, as water supply needs expand and greater distances are involved in bringing water supplies to points of service, it is expected that more and more pumping plants of major size and higher lifts will be necessary. Thus, there are greater prospects in the area of pump develop-

TABLE 5.—*Selected examples of penalty clauses for losses in efficiency included in invitations to bid*

Plant	Total capacity	Penalty for 1-percent efficiency loss	
		Energy	Capacity
Glen Canyon powerplant..........kilowatts..	900,000	$670,000	$1,070,000
Judge Francis Carr powerplant..........do....	134,000	[1] 157,000	[1]
Dos Amigos pumping plant..........horsepower..	240,000	92,500	95,000
Flatiron pumping plant..........do....	13,000	12,500	12,500

[1] Combined value representing a loss in both components.

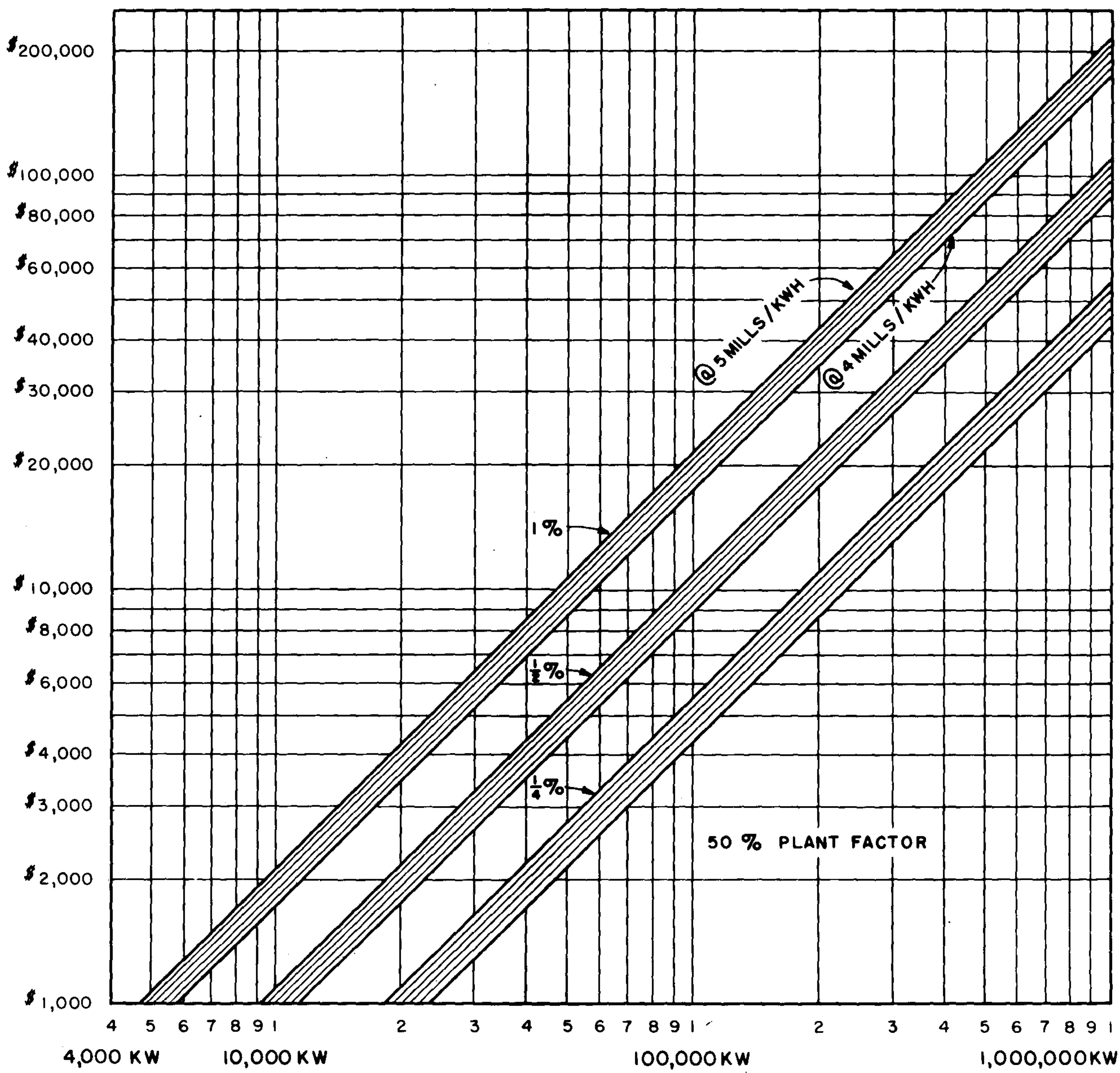


FIGURE 6.—*Potential benefits from small increases in efficiency for first year of operation for turbines and pumps sized from 4,000 to 1,000,000 kilowatts.*

ments for the realization of improvements in efficiencies by virtue of having a simple, inexpensive, and accurate method of measuring discharges under high pressure.

To provide a general guide on potential increases in electrical production or savings in energy, several value curves were developed to represent a wide range of plant sizes of from 1,000 to 1,000,000 kilowatts. These general indicators are useful for both powerplants and pumping plants. Pumping plants normally referred to in terms of horsepower can be easily converted to its electrical equivalent (1 horsepower equals 0.746 kilowatt). The curves cover increases in efficiency of one-fourth, one-half, and 1 percent and a band to show values at 4 and 5 mills per kilowatt-hour assuming an overall plant factor of 50 percent. As demonstrated in figure 6 the benefits, read on the left scale, are sensitive to installed capacity as it requires a 1-percent gain in efficiency and a minimum of 5,000 kilowatts to produce an annual benefit of about $1,000.

Abstract

This report presents a broad-brush study identifying the economic potentials of using radioisotopes for measuring high-pressure waterflows through turbines and pumps. A need exists for a highly accurate, simple, and inexpensive means for measuring waterflows. Other promising alternative measuring devices not using radioisotopes may warrant further consideration. The main object of this study is to determine reasonable expectations of benefits to be derived if this potential new tool successfully meets its goals. Possible economic gains by applying radioisotope water measurement to Bureau of Reclamation programs appear attractive. A brief appraisal of alternative methods now used for measuring waterflows through turbines and pumps reveals that much savings in test expenses could be attributed to the radioisotope method. Better and more accurate information permitting greater selectivity and control of individual units at a given site, or geographically separated installations, could permit fuller use of design capabilities of machines and the institution of more timely maintenance programs.

DESCRIPTORS—*turbines/ *pumps/ efficiencies/ *flow measurement/ field tests/ *radioisotopes/ powerplants/ pumping plants/ benefits/ penstocks/ cost comparisons/ hydroelectric plants/ discharge measurement/ salt-velocity method/test procedures.

IDENTIFIERS—*accuracy.

U.S. GOVERNMENT PRINTING OFFICE: 1969 O—329-308