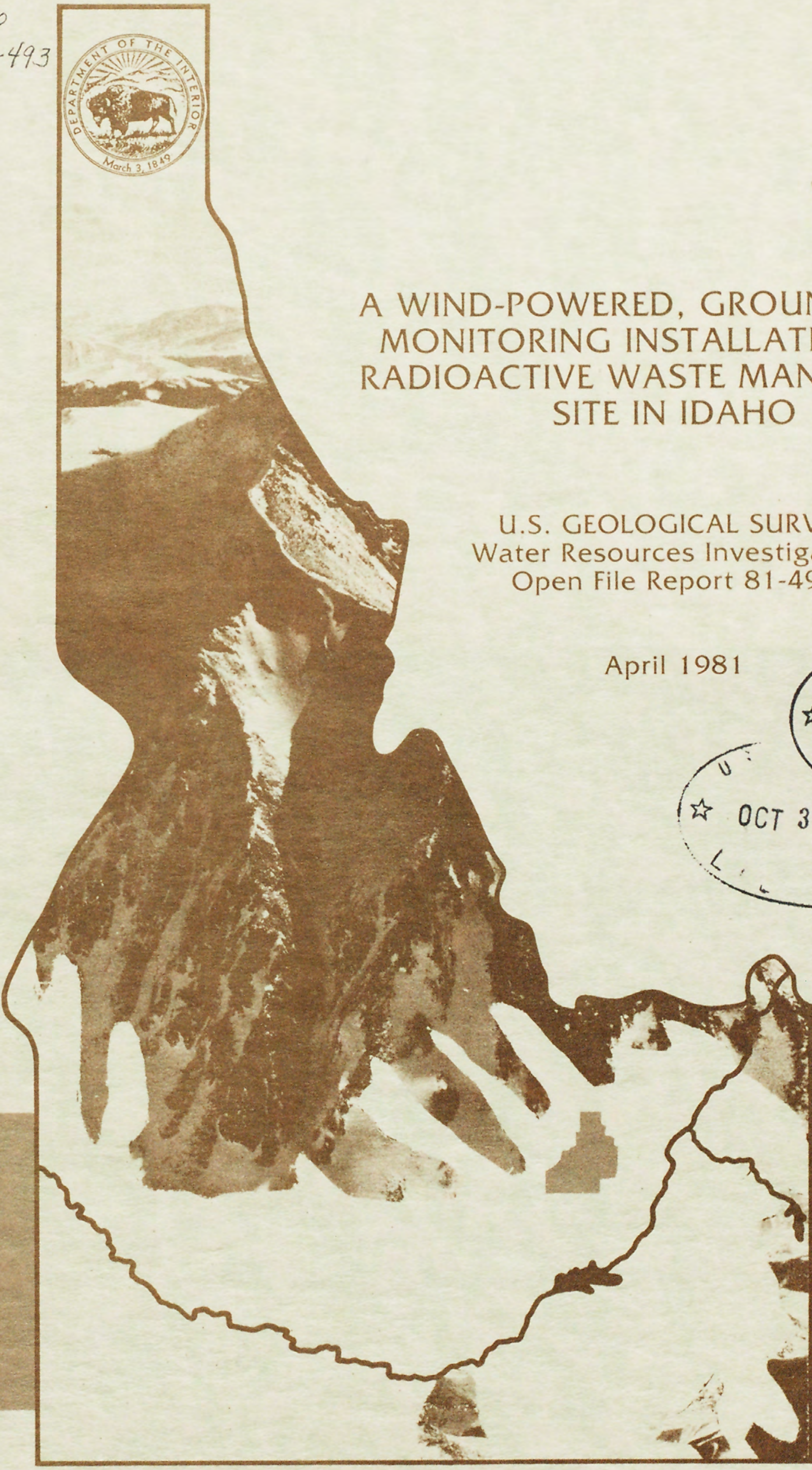

IDO-22059

A WIND-POWERED, GROUND WATER MONITORING INSTALLATION AT A RADIOACTIVE WASTE MANAGEMENT SITE IN IDAHO

U.S. GEOLOGICAL SURVEY
Water Resources Investigation
Open File Report 81-493

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY

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UNITED STATES DEPARTMENT OF THE INTERIOR
JAMES G. WATT, Secretary
GEOLOGICAL SURVEY
Doyle G. Frederick, Acting Director

For additional information write to:

U.S. Geological Survey
Water Resources Division
Project Office,
Idaho National Engineering Laboratory
CF-690, Room 164, P.O. Box 2230
Idaho Falls, Idaho 83401

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ILLUSTRATIONS

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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

The following factors can be used to convert inch-pound units published herein to the International System (SI) of metric units.

Multiply inch-pound units	By	To obtain metric units
feet (ft)	0.3048	meters (m)
inches (in)	25.40	millimeter (mm)
miles (mi)	1.609	kilometers (km)

temperature, degrees Celsius (^{o}C) = 0.556 (^{o}F-32)

The use of company names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

A WIND-POWERED, GROUND WATER MONITORING INSTALLATION AT A RADIOACTIVE WASTE MANAGEMENT SITE IN IDAHO

By

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ABSTRACT

In 1971, four wells were drilled just outside a radioactive solid waste storage and disposal facility located on the Idaho National Engineering Laboratory in southeastern Idaho. This facility, the Radioactive Waste Management Complex (RWMC), has been in use since 1952. These wells serve several purposes: to study the geology and hydrology at the RWMC, to determine the potential for radioactive waste migration, and to obtain water samples to determine if waste products are migrating downward into the Snake River Plain aquifer.

Special efforts are made to insure that surface contamination does not enter the wells by either water, wind, or contaminated equipment. A submersible pump and a continuous water-level measuring device were installed in each well. Permanent installation of this equipment allowed the well heads to be sealed while providing for collection of data from these wells.

The water-level measuring device is a small diameter, differential-pressure, transducer probe. The transducer produces a variable-reluctance signal which is converted to an analog signal and recorded as the depth to water on a strip chart recorder. Windmill-charged storage batteries provide power for the water-level measuring system. This system is reliable, sensitive, and relatively maintenance free.

INTRODUCTION

The Idaho National Engineering Laboratory (INEL) is an 890 square mile (2,290 km^2) nuclear research facility located on the Snake River Plain in southeastern Idaho. Near the southern boundary of the INEL is the Radioactive Waste Management Complex (RWMC) where radioactive wastes are buried or temporarily stored (fig. 1).

Previous studies by the U.S. Geological Survey (Barraclough and others, 1976), have investigated possible subsurface migration of buried wastes at the RWMC. For these studies, ten wells were drilled. Six shallow wells were drilled within the RWMC perimeter to obtain core samples. Four deeper wells, 87, 88, 89, and 90 (fig. 2) were drilled outside the RWMC perimeter to collect water samples from the Snake River Plain aquifer which is 580 feet (177 m) below the RWMC. Construction details of wells 87, 88, 89, and 90 are shown in figure 3.

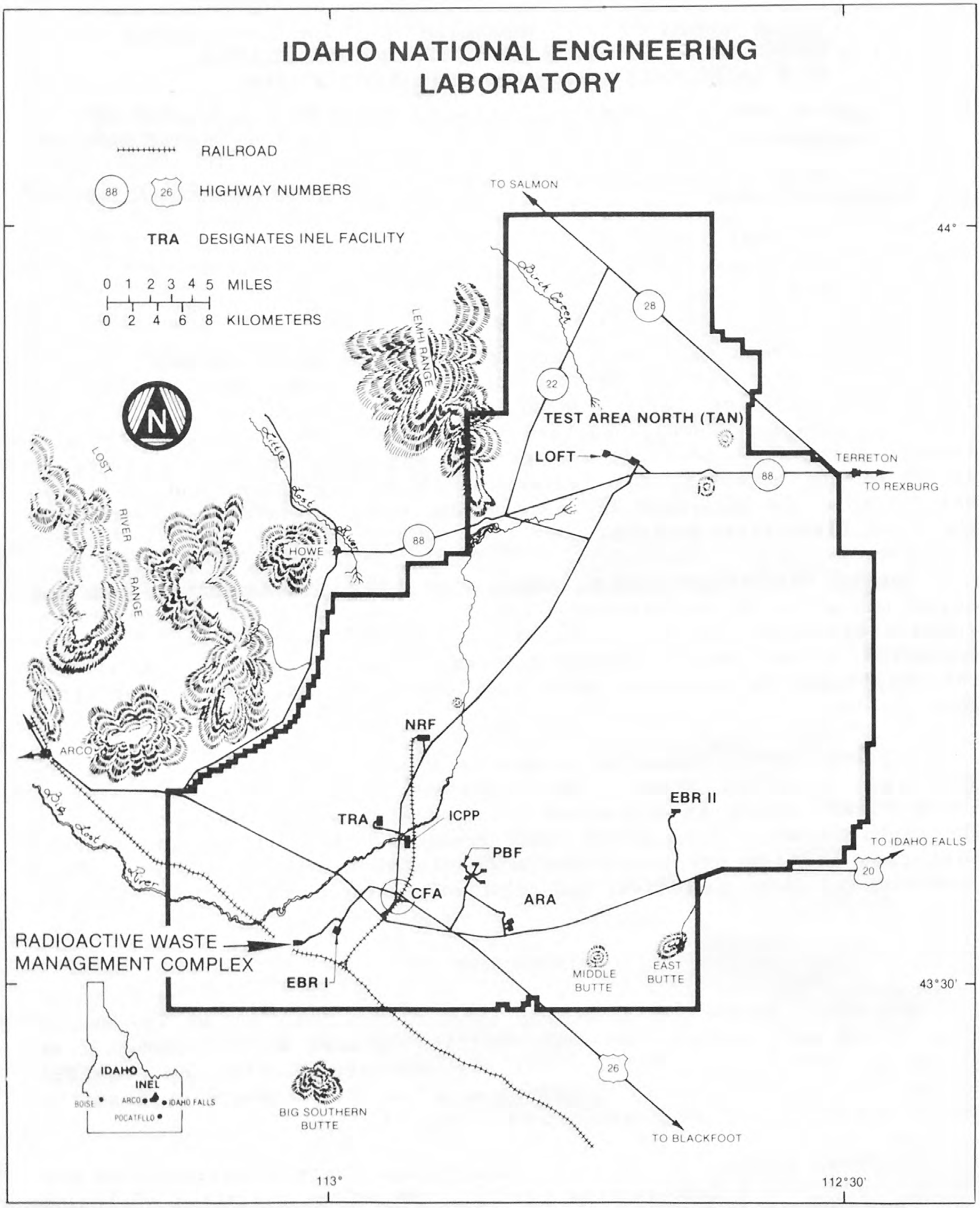

Figure 1.--Map showing location of study area.

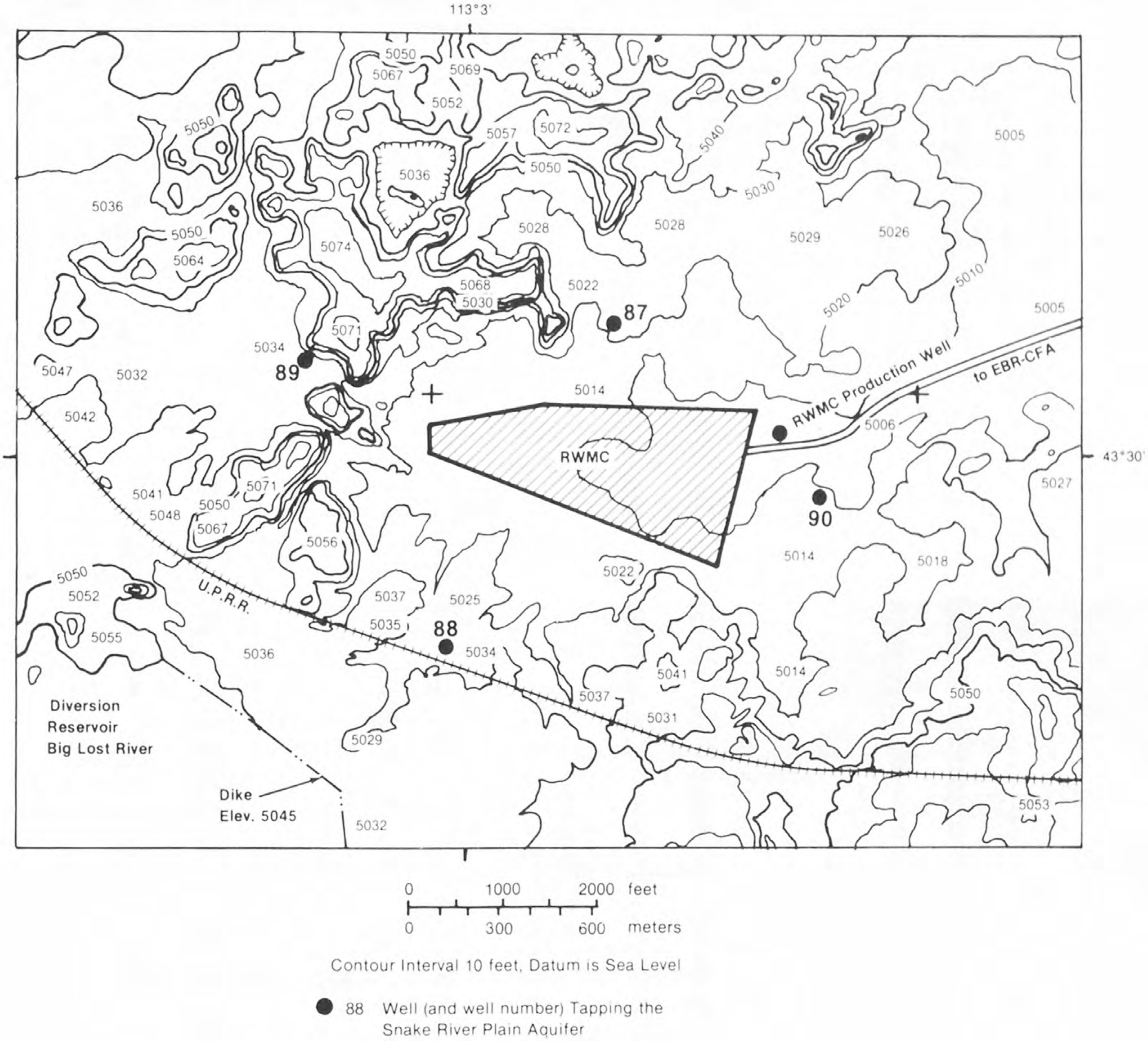

Figure 2.--Topographic map of the RWMC and a part of the Big Lost River ponding area.

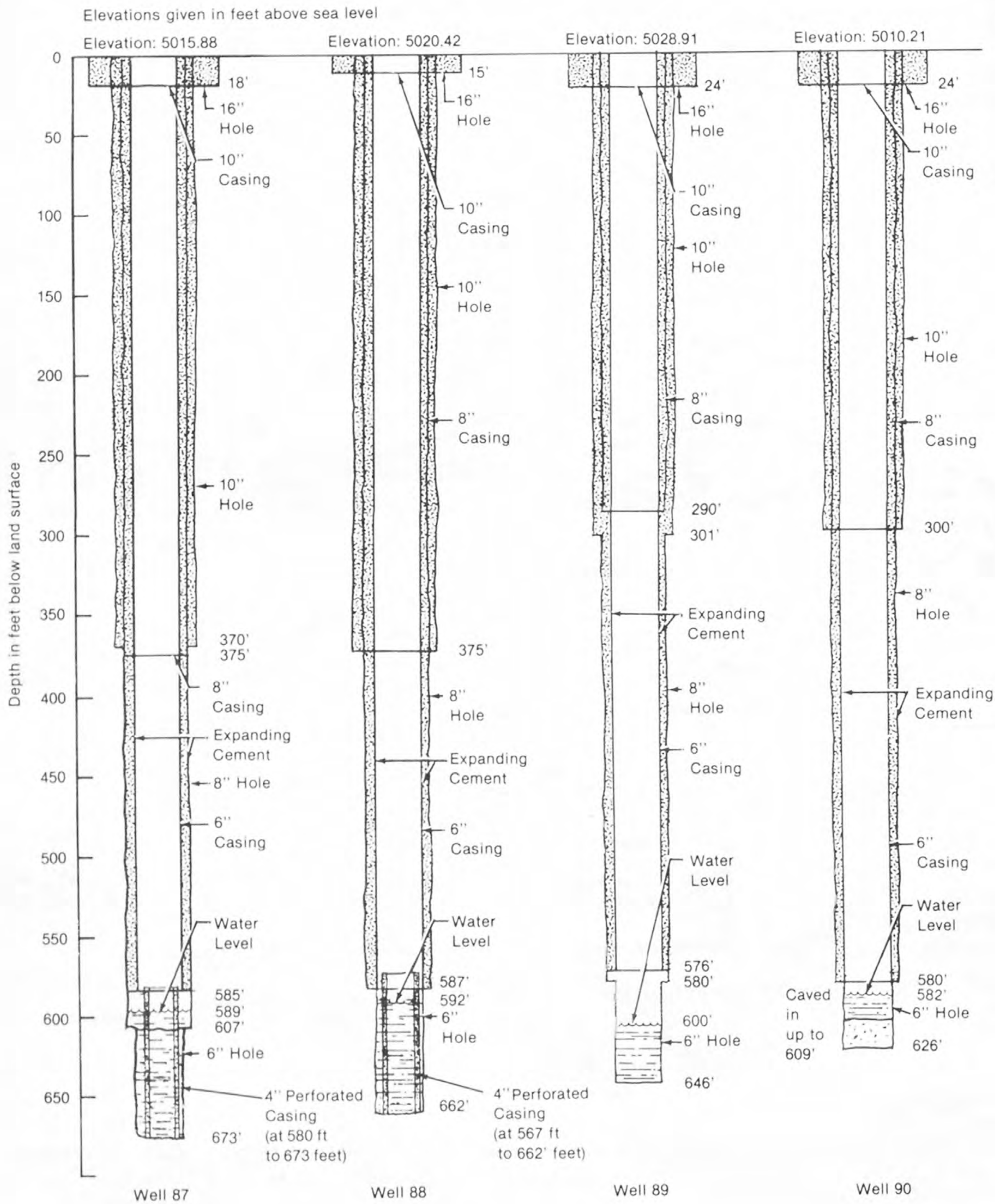

Figure 3.--Construction diagrams for wells 87, 88, 89, and 90.

While drilling these wells, care was taken not to introduce any radioactive contamination from the surface into the well bore. Laboratory detection limits for radioactive materials are so low that even very small radioactive dust particles may cause a sample to have a positive reading. Earth moving equipment at the RWMC may stir up this slightly contaminated dust; therefore, keeping this dust out of the wells is essential if results are to be valid.

A submersible pump and a transducer probe were installed in each well. The well head was then sealed to eliminate the possibility of surface contamination entering the wells. The submersible pump allows water samples to be collected, and the transducer probe provides continuous water-level measurements which are recorded at the surface.

The wells were remote from existing power sources, so a windmill-battery system was designed and installed to power the water-level recorder at each well. When a water sample is taken, power for the sampling pump is supplied by a portable electric generator installed on the water sampling truck.

The purpose of this report is to explain why this system was chosen, how it was installed, how it operates, what problems were encountered, and how such a system is built.

Acknowledgments

Appreciation is extended to the personnel of the Department of Energy and the various manufacturers for their technical support.

HYDROGEOLOGY

The rocks beneath the RWMC are principally basalt. Sediments deposited by wind and water occur at the surface and in beds between some basalt flows. Two principal sediment beds occur, one at about 110 feet (34 m) and the other at 240 feet (73 m) below the land surface. The average thickness of the surficial sedimentary layer is about 15 feet (4.6 m) while that of the two principal subsurface sedimentary layers is 13 and 14 feet (4.0 and 4.3 m), respectively (Barraclough and others, 1976). The water table beneath the RWMC is at a depth of about 580 feet (177 m).

WATER SAMPLING PROGRAM

The Snake River Plain aquifer below the INEL is monitored by the U.S. Geological Survey for the U.S. Department of Energy. Water-level measurements and water samples are taken regularly from a network of wells across the INEL. Water-level measurements are used to determine changes in aquifer storage. Water sample analyses are used to monitor the locations of radioactive waste plumes in the aquifer and to update a digital-computer model which projects future concentrations and locations of the waste plumes (Robertson, 1974).

Most radioactive waste entering the ground water system at the INEL does so through a waste disposal well at the Idaho Chemical Processing Plant (ICPP) and through seepage ponds at the Test Reactor Area (TRA) (fig. 1).

Water-level measurements in the RWMC wells indicate that occasionally a ground-water mound exists in the area south of the RWMC which causes a localized reversal in the normal direction of ground-water flow (Barraclough and others, 1976). The ground-water mound is caused by aquifer recharge from the INEL flood diversion system on the Big Lost River. Pumping of the RWMC production well may also influence the flow line direction.

Water samples are taken quarterly from the RWMC monitoring wells. These samples are analyzed for tritium (^{3}H), strontium-90 (^{90}Sr), americium-241 (^{241}Am), plutonium-238 (^{238}Pu), and plutonium-239-240 ($^{239,240}Pu$) concentrations. The specific conductance of the water is measured and a gamma scan is run to detect the possible presence of gamma-emitting isotopes.

MEASURING SYSTEM SELECTION

There were two special requirements on the choice of a water-level measuring system. First, equipment must not introduce or allow any contaminants to enter the well. This consideration ruled out conventional methods for measuring water levels. Measuring devices lowered from the surface could be contaminated. Second, the water levels must be measured in small diameter wells which are crowded with the pump, pipes, and electrical cables.

It was determined that a differential-pressure transducer probe installed below the water level in each well satisfied these requirements. The transducer probe has a small diameter, a low power requirement, and provides the necessary sensitivity of 0.01 foot $\pm$ 0.01 foot. Figure 4 shows a photograph of the transducer used in these wells.

The water level is measured by a pressure sensitive diaphragm within the transducer. A change in the water level causes a change in pressure which in turn causes a corresponding change in the output voltage across the diaphragm. A specific diaphragm output voltage is calibrated to a specific water depth. The water depth is recorded on an analog, strip-chart recorder.

This transducer-recorder system requires either a 120-volt AC or 12-volt DC power supply. Well 87, the first well to be instrumented, was provided with a 120-volt AC power supply. The cost of constructing an AC power line to the well site was high. Since the length of the electric power lines to the other three wells would be longer, an alternate power supply was investigated.

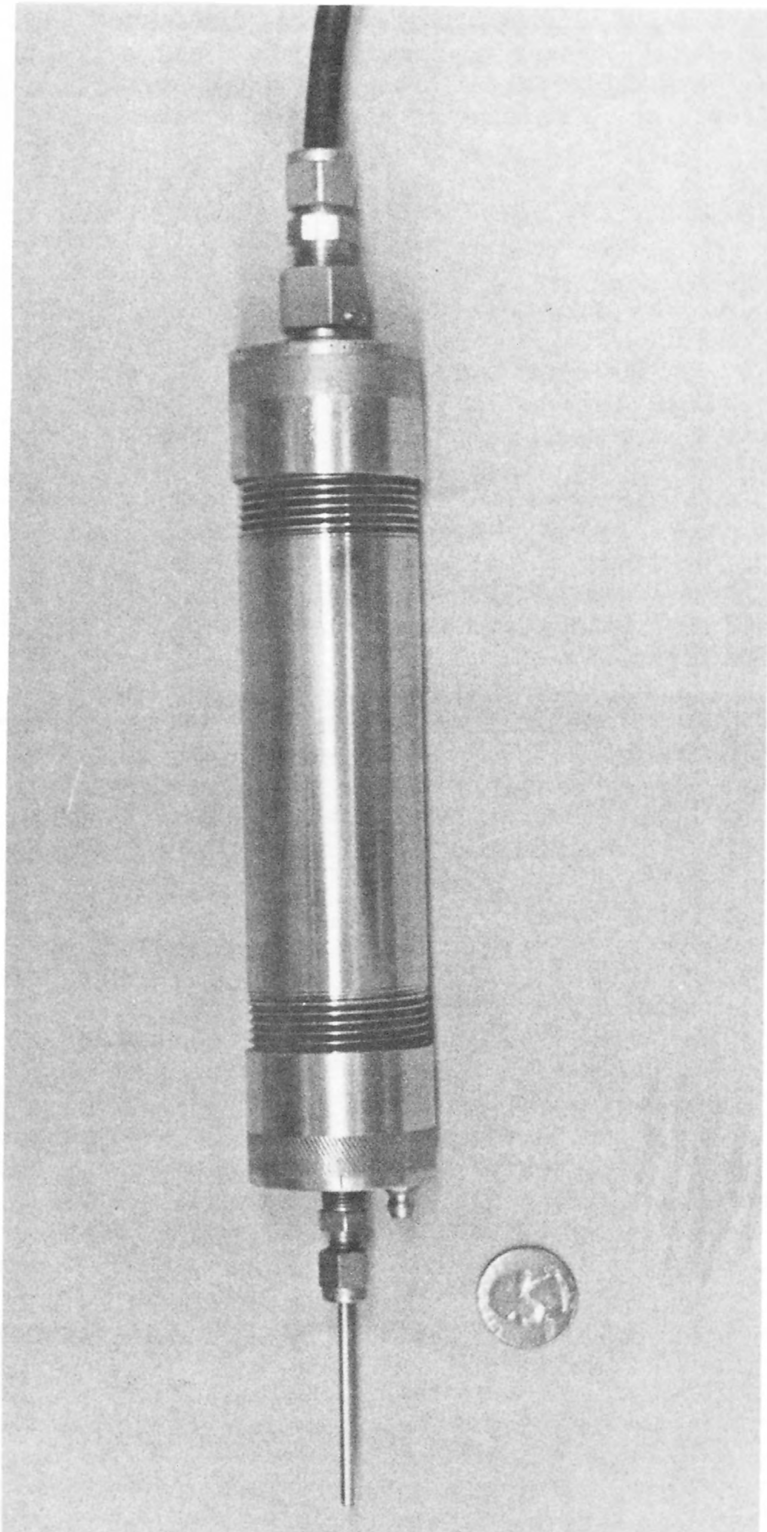

Figure 4.--Photograph of transducer probe.

After considering storage batteries, generators, solar power, and windmills, a windmill-battery combination was found to be the most economical and to require the least maintenance. This system has performed well and is not affected by occasional AC power failures.

INSTRUMENTATION SYSTEM DESIGN AND CONSTRUCTION

Instrument Shelter

The instrument shelters installed at wells 87 through 90 are large, heavy-duty permanent type shelters measuring 6x6 feet by 7 feet tall (fig. 5). The shelters are constructed of 2x4 inch frame walls, insulated to R-19, and 2x6 inch frame floor and roof, which are also insulated (the shelters were originally designed to be heated). The shelter interiors are lined with 1/2-inch plywood, have one 1x12x48 inch instrument shelf, and have a hole in the floor for the well casing. The shelter exteriors are covered by cellotex sheathed with aluminum camper siding and the roofs are 1/2-inch plywood covered by asphalt rolled roofing. The shelters have a sturdy, locking, front door.

Prior to installing shelters, a concrete foundation pad was poured around the well casing. The shelters were then installed by forklift. Each shelter was bolted directly to the concrete pad to prevent the wind from blowing them over.

Well Construction

Multiple casings in wells 87, 88, 89, and 90 were pressure cement grouted from the surface to the water table (fig. 3). This cement grout stabilized the well bore and prevents waste from migrating downward in the well bore. A previous report by Barraclough and others (1976) described well construction in detail.

A 1-1/2 horsepower submersible pump was installed in each well at the depth indicated in table 1. Then, 1-1/2-inch galvanized steel measuring lines were installed. The bottom of each measuring line was fitted with a guide consisting of a 1-1/2-inch to 1-inch bell reducer and a short piece of 1-inch pipe. The lower end of the 1-inch pipe and both ends of all the measuring line couplings were beveled to prevent the measuring line from stripping or shearing the pump's electric cables (fig. 6). A measuring line is necessary in order to lower the water-level measuring transducer into the well without tangling with the pump's electric cables.

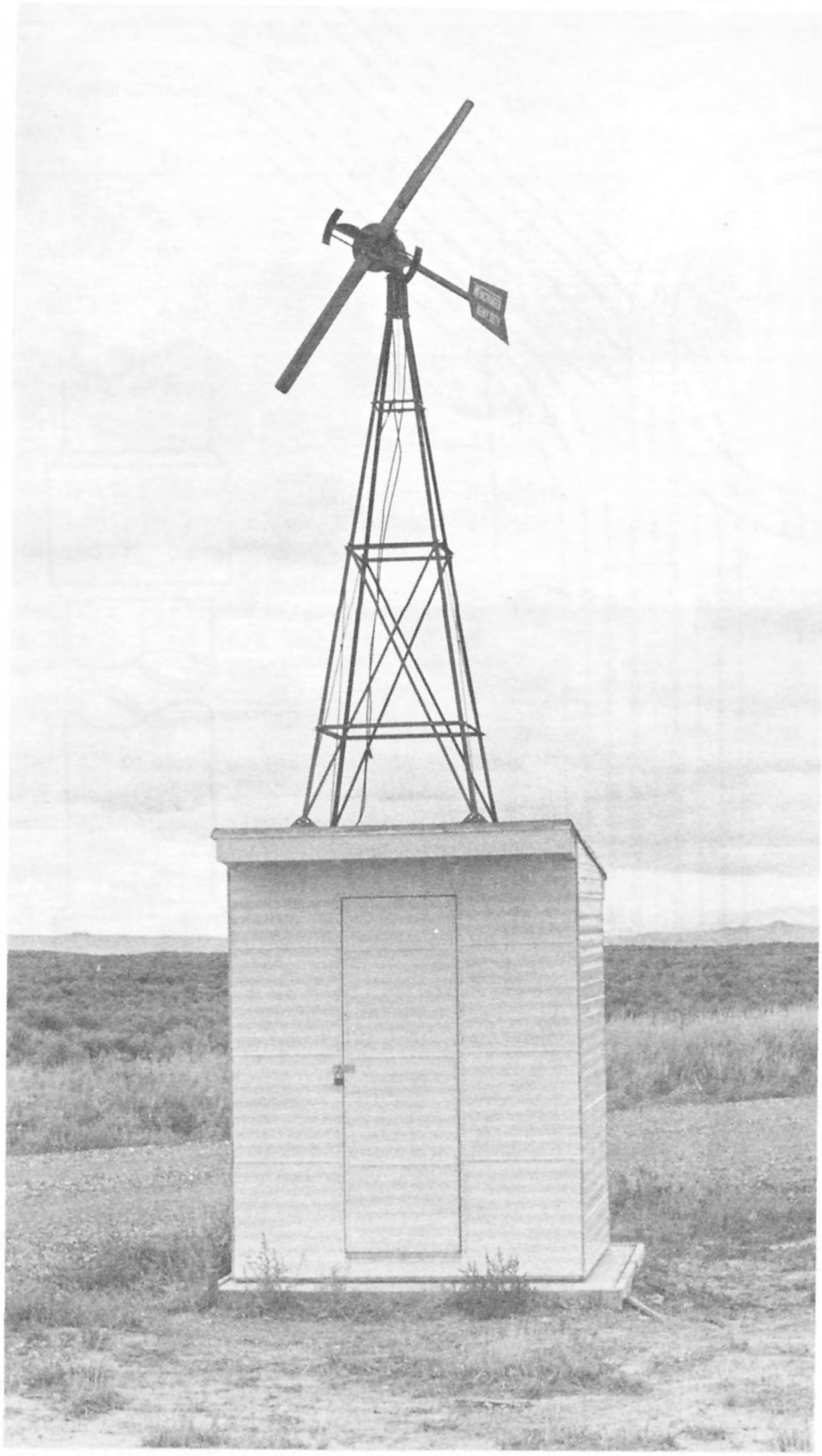

Figure 5.--Photograph of instrument shelter at well 89.

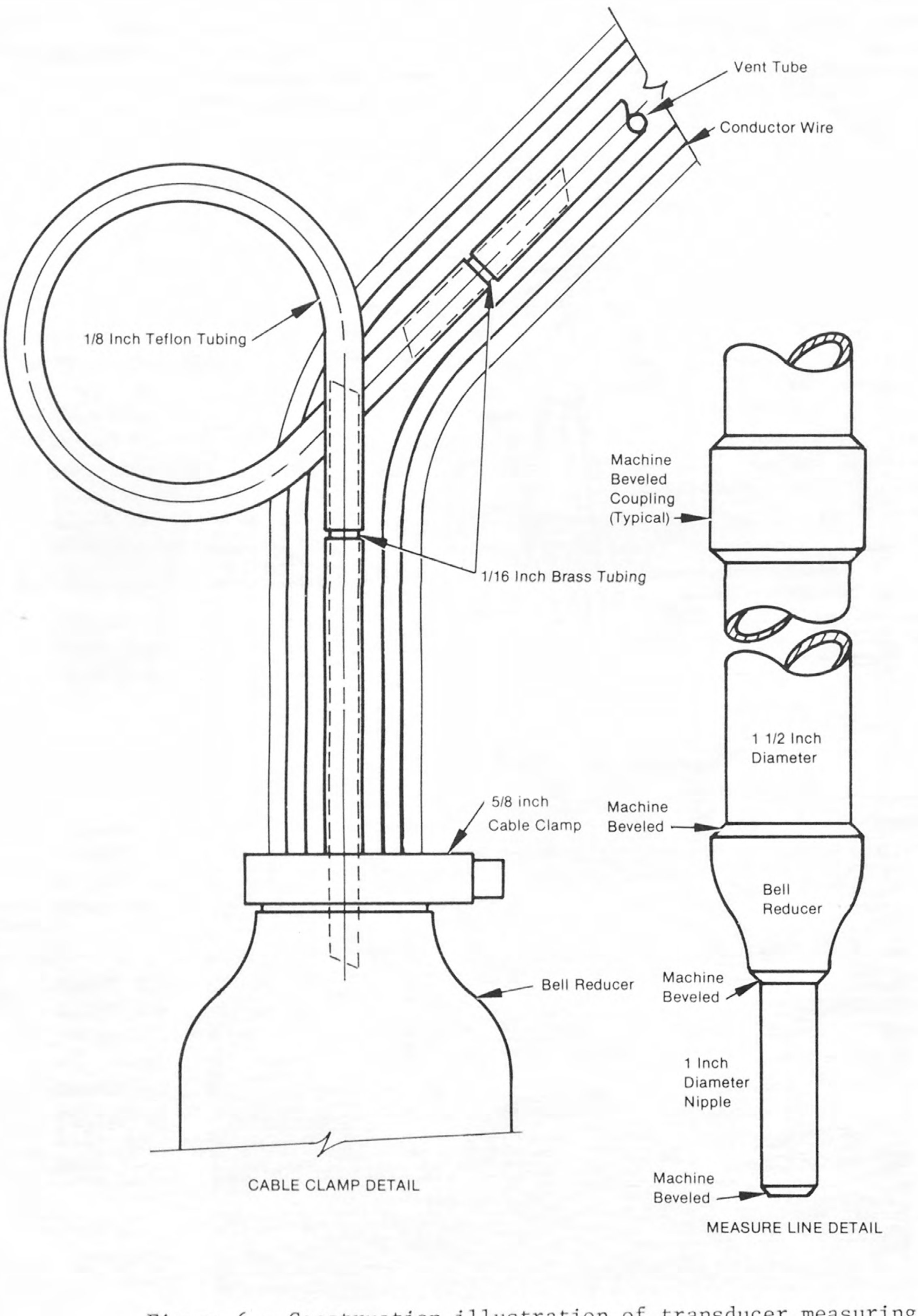

Figure 6.--Construction illustration of transducer measuring line and surface cable clamp detail.

Table 1.--Pump and transducer depths

Well No.	Depth of Well (feet)	Average Depth to Water (feet)	Depth to Top of Pump (feet)	Depth of Transducer (feet)
87	673	589	608	600
88	662	592	609	602
89	646	600	615	610
90	626	582	599	592

Transducer System*

Diaphragm-type pressure transducer designs are based on the magnetic-reluctance principle and offer a number of advantages in pressure measurement and control. These include:

1. Excellent dynamic response characteristics with liquid as well as gas systems due to high natural frequency, low volumetric displacement and low internal volume.

2. Ability to accept corrosive liquids and gases on both sides for differential pressure measurement without isolation of the transducer.

3. Extreme overload tolerance--operator proof.

4. Ability to withstand severe shock and vibration.

5. High level output.

6. High noise immunity.

In a pressure transducer, shown in figures 7 and 8, a diaphragm of magnetically permeable stainless steel is clamped between two blocks and deflects when a pressure difference is applied through the pressure ports illustrated. An E shaped core and coil assembly is embedded in each block with a small gap between the diaphragm and the E core, in a symmetrical arrangement, resulting in a condition of equal inductance with the diaphragm in an undeflected position. Deflection of the diaphragm results in a change in inductance of the two coils, one increasing and the other decreasing.

*Information regarding the theory, operation, and technical specifications of the variable-reluctance transducer system is provided courtesy of Validyne Engineering Corporation.

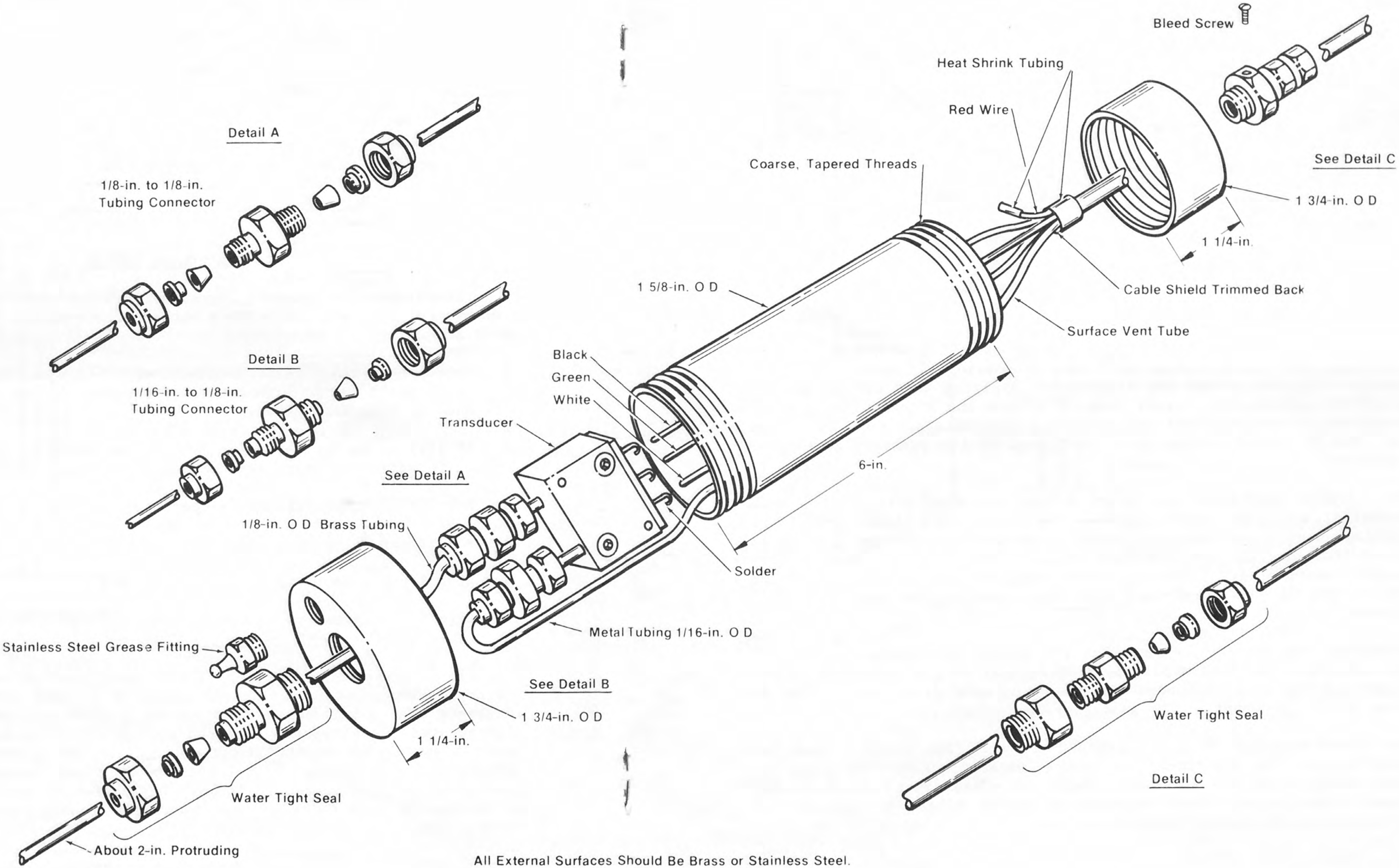

Figure 7.--Transducer housing.

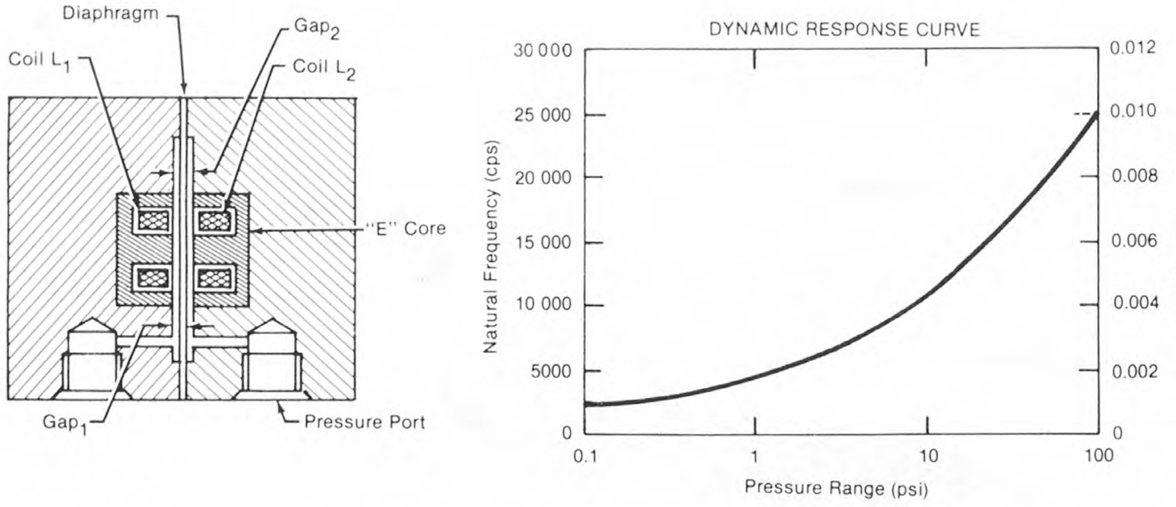

Figure 7. Transducer Pressure Diagram.

When the coils are connected in a bridge circuit and are excited by an AC voltage, the output voltage will vary proportionally to the differential pressure applied across the diaphragm. Applying this output voltage to the carrier demodulator circuit (fig. 9) allows the AC output voltage of the transducer to be amplified and rectified (demodulated) to a DC output voltage. The DC output voltage is proportional to the pressure applied to the transducer.

The carrier oscillator is a low distortion Wien Bridge-type, with a differential amplifier level sensor. Use of a field effect transistor as a voltage-controlled resistor causes a balance of the bridge. Both oscillator frequency and amplitude are regulated by a stable, temperature-compensated, zener diode. The oscillator supplies 5.0 volts at 5 thousand Hertz sine wave to the transducer from the center tapped secondary of a transformer.

Grounding the center tap completes the transducer bridge circuit and produces an output which is amplitude proportional to the unbalance of the transducer and is sense dependent in the unbalance direction. This AC output is fed to the input of the amplifier/demodulator.

The output voltage from the transducer, the ZERO control, and the auxiliary balance pin, are summed into a span potentiometer. The potentiometer center tap feeds the AC voltage amplifier which drives the demodulator stage. The output stage utilizes an active filter to control the carrier ripple on the carrier demodulator output.

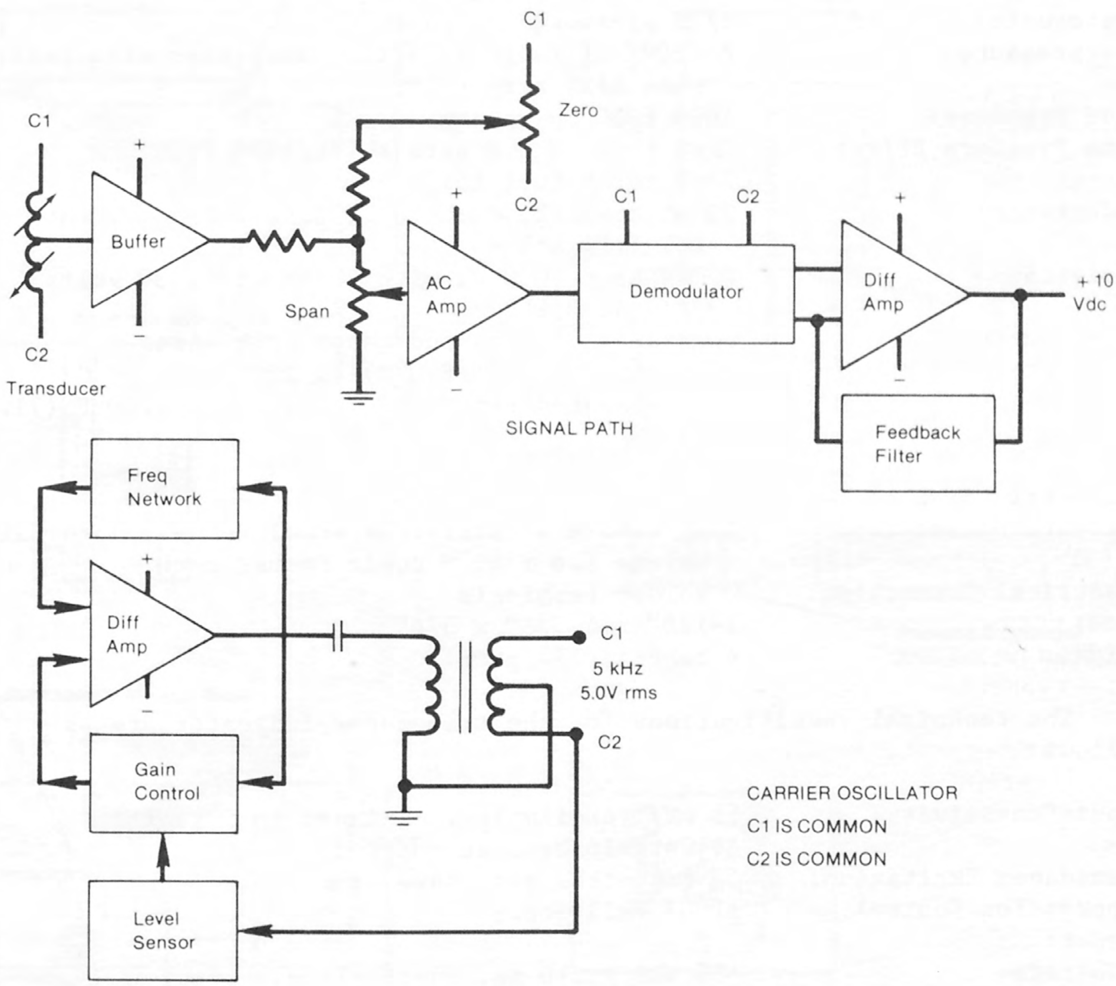

Figure 9. Simplified carrier demodulator.

The technical specifications for the transducer used in this system are as follows:

Standard Ranges:	±15 psi differential
Linearity:	±1/2% best straight line
Hysteresis:	1/2% pressure excursion
Overpressure:	To 200% of range in either direction with less than 1/2% zero shift
Line Pressure:	1000 PSIG operating
Line Pressure Effect:	Less than 1% F S zero shift/1000 PSIG
Output	25mV per V full scale nominal
Inductance:	20 mh nominal, each coil, zero balance within 10% full scale
Excitation:	1,000 to 20,000 Hz with 20 mh coils 30 volts max. at 3,000 Hz
Pressure Media:	Corrosive liquids and gases both sides
Temperature:	Operating--65°F (18.3°C) to 250°F (121.2°C) compensated range 0°F (-17.8°C) to 160°F (71.2°C).
"O" Rings:	Buna N
Pressure Cavity Volume:	2.6×10^{-3} cubic inch
Volumetric Displacement:	1.2×10^{-4} cubic inch
Pressure Connection:	1/8" O.D. x 1" stainless steel tubes. Internal volume 6.6×10^{-3} cubic inches each
Electrical Connection:	3 solder terminals
Size:	1-1/8" x 1-3/8" x 3/4"
Weight:	4 ounces (114 gram)

The technical specifications for the transducer indicator are as follows:

Input Sensitivity:	15 mV/V excitation, minimum, full scale. Adjustable by span control
Transducer Excitation:	5V rms, 5kHz sine wave
Suppression Control:	±100% Full Scale
Output:	
Voltage:	±10 VDC at 10 ma, Short circuit proof
Output Impedance:	10 ohms, nominal
Frequency Response:	Selectable 0-10, 0-50, 0-200 0-1000 Hz, Flat ±10%
Stability:	±0.1%/30 days
Ripple:	Less than 10mv peak to peak
Zero Drift:	±0.005%/°F. Average
Temperature Range:	0-185°F
Power Requirements:	105-125VAC, 50-400Hz, 5 Watts, nominal or 12 volts DC
Weight:	4 pounds 10 ounces avdp (2.1 kg)

The transducer (fig. 10) is installed in the tranducer housing (fig. 7) in the following sequence:

1. Insert the surface cable through the housing top cap assembly and push clear through the housing tube.

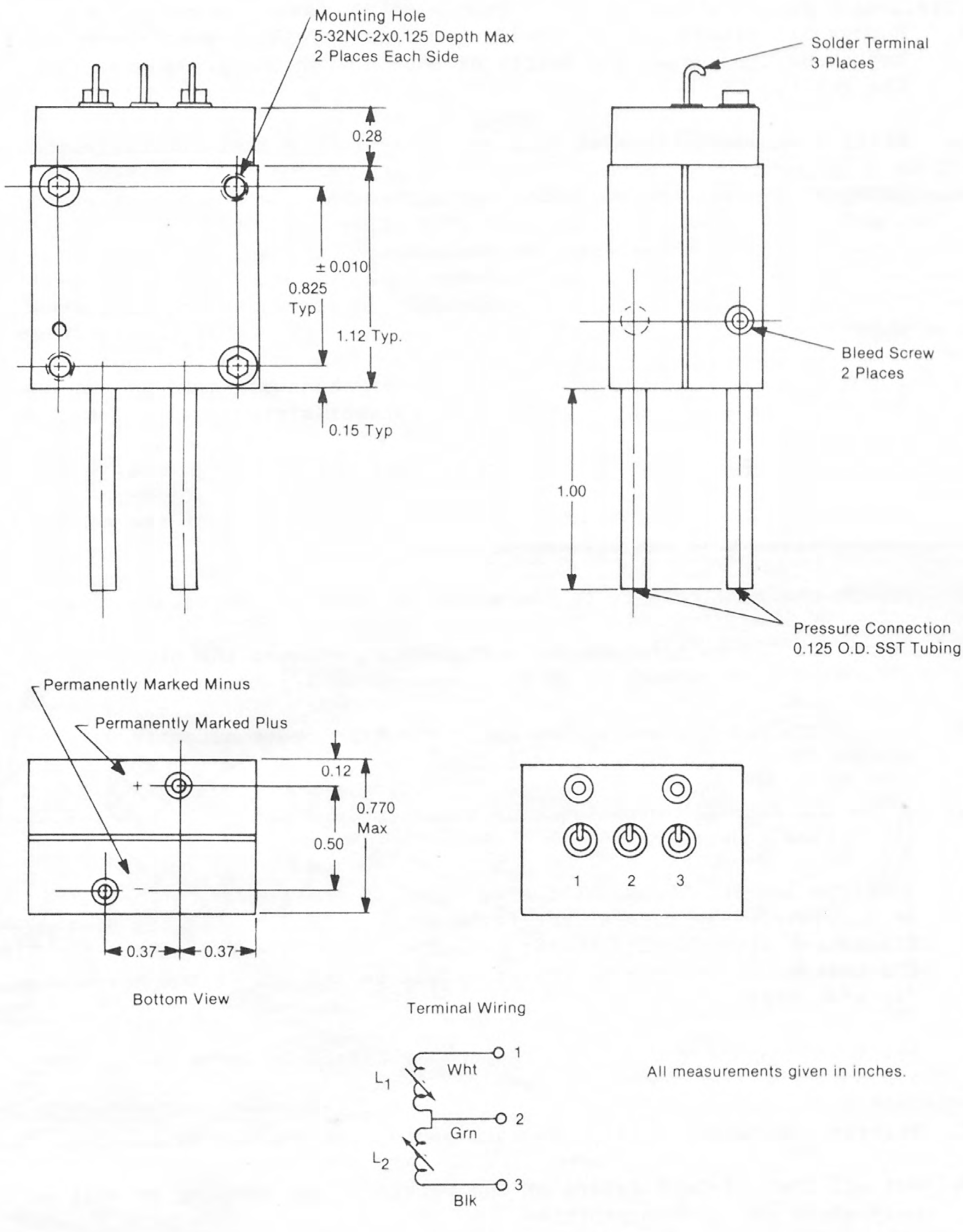

Figure 10.--Transducer diagram.

2. Strip the cable about 3 inches to bare the 4 conducting wires inside.

3. Remove all exposed cable shielding. This shielding must not contact any conducting materials (wires or housing) on the probe end of the cable.

4. Slide a one-inch piece of heat shrinking tubing over the cable end.

5. Slide wire size heat shrinking tubing over the conducting wires.

6. Solder the conducting wires to their corresponding terminals.

7. Push a candy-cane shaped piece of 1/16-inch brass tubing into the plastic surface vent tubes.

8. Slide the heat shrinking tubings to cover the cable end and the solder terminals. Heat them until they shrink tight.

9. Screw the top housing cap all the way onto the housing tube.

10. Attach the 1/16 to 1/8-inch reducer to the other end of the candy-cane shaped brass tube and tighten it snugly.

11. Attach the same reducer to the minus (-) side of the transducer.

12. Using the 1/8 to 1/8-inch brass connector, connect the plus (+) side of the transducer to an 8-inch piece of 1/8-inch brass tubing.

13. Pulling on the surface cable, guide the transducer assembly part way into the transducer housing tube.

14. Slide the 1/8-inch plus (+) side brass tubing through the center of the bottom housing cap.

15. Bend the 1/8-inch brass tubing as close to the transducer coupling as possible being careful not to bend the tubing coming out of the transducer itself. The tubing should be bent only far enough to allow the bottom housing cap to center itself on the end of the transducer (+) side tube.

16. While pulling very gently on the cable, carefully screw the bottom cap onto the transducer housing.

17. Tighten the brass fittings on each end of the transducer housing.

18. Cut off the 1/8-inch tubing on the bottom of the housing so that only about two inches protrude.

19. While holding the transducer housing in an upright position, fill the transducer housing with silicon grease that has been allowed to warm to room temperature. Prior to filling, be sure that the vent screw has been removed from the top of the transducer housing.

20. Once the grease comes out of the vent screwhole, stop filling. Let any excess grease trickle out the filling hole and reinstall the vent screw.

Cable

Water-level fluctuations in the RWMC wells are normally 2 to 3 feet per year. The transducers were installed about 10 feet below the average water level for each well. To measure the length of cable required (fig. 11), roll out the cable after the transducer has been installed at one end and put a piece of masking tape around the cable at the desired length to be lowered into the well. It is important at this point to consider the height of the measuring point above the land surface and add an appropriate amount of cable to compensate for it. Once the masking tape has marked the proper depth on the cable, add sufficient cable length to run to the instruments and cut the cable off at this point.

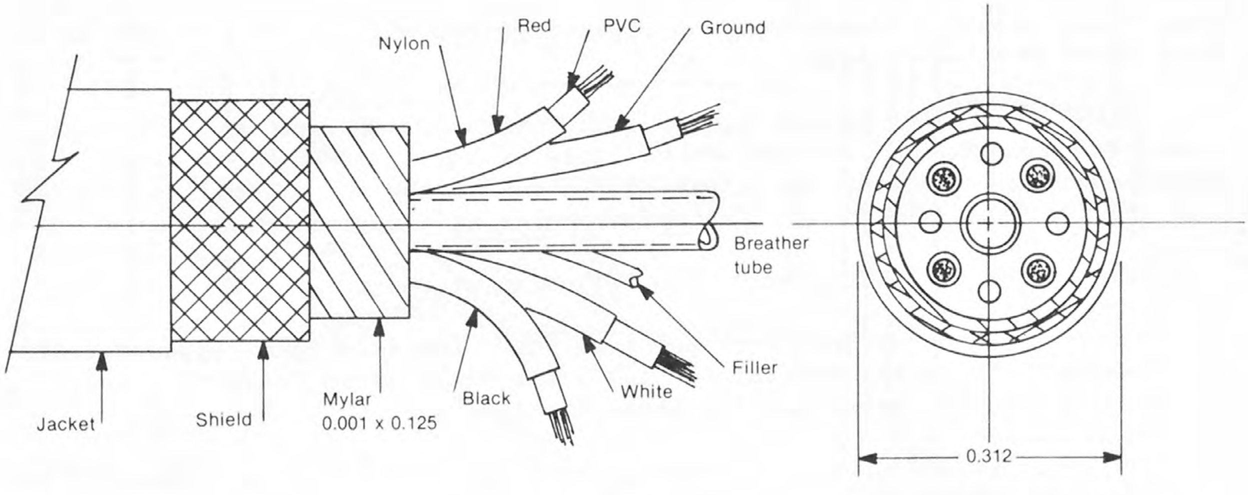

Figure 11.--Cable diagram.

Installation and Calibration

It is advisable to test the transducer and recorder system before lowering the transducers in the well. The test for proper operation is done as follows: connect the transducer, cable, indicator, recorder, and dessicator as shown in figure 12. Turn the system on and let it warm up for about five minutes, adjust the transducer indicator to zero, adjust the recording pen to the center of the chart, and apply a small pressure or suction to the desiccator vent tube. If the transducer is functioning properly, pressure should deflect the recording pen one direction and suction the other. There may be a brief time lag between the change in pressure and the stabilization of the recording pens. If the system appears to be working properly it may be placed in the well and calibrated. If it does not function properly, review the assembly and test instructions and try again.

At the well site, slide a bell reducer and a cable clamp over the surface end of the cable (fig. 6) and down past the masking tape. About 1/2-inch above the tape, carefully cut open the cable. Do not cut any of the internal wires or insulating cables. Cut the vent tube in half (fig. 6). Insert a 3-inch long piece of 1/16-inch brass tubing into the transducer side of the vent tube until only one inch of it is visible. It is very important that the brass tubing extends all the way under the masking tape. This prevents the cable clamp from collapsing the surface vent tube. Insert two inches of 1/16 inch tubing into the other half of the vent tube. Connect these two vent pipes together with a 1/8-inch flexible tube about six inches long.

Clamp the cable clamp snugly over the masking tape and carefully lower the transducer into the well. This requires two people. When the cable clamp is reached, the clamp will rest on top of the bell reducer. Now complete the rest of the surface hook-ups as illustrated in figure 13.

The system is calibrated by the following steps:

1. Set the transducer indicator power to "ON", the frequency response to "NORMAL", the meter sensing to "10%", the suppression to "NONE", and with the zero control set the meter to "ZERO".

2. The recorder is turned "ON", the span set to "1 volt", the attenuator to OFF, and the chart speed to 0.5 cm/hr.

3. Zero the recorder pen to a vertical chart division line located in the center of the chart.

4. Raise the transducer exactly 12 inches and observe the travel of the recorder pen.

5. While the transducer is raised, adjust the transducer indicator span knob so that the recorder pen is now at the chart division that you wish to have represent a 12-inch water level <u>drop</u>.

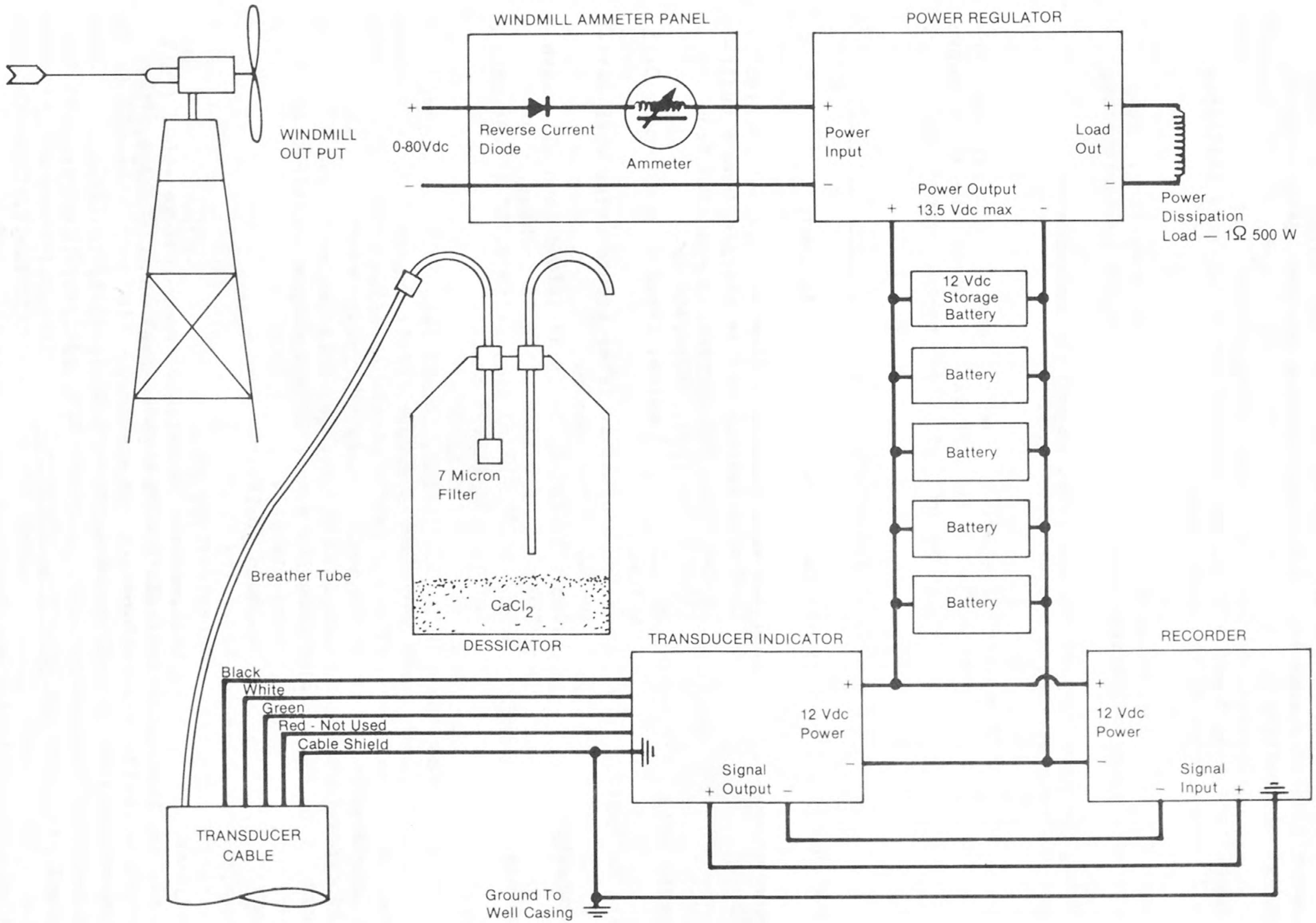

Figure 12.--Surface electronics wiring diagram.

6. Lower the transducer to its original position and adjust the transducer indicator zero knob until the recorder pen has returned to its original position.

7. Repeat steps 4, 5 and 6 until the recorder pen accurately indicates a 12-inch change in the water level.

8. With a steel tape, measure the water level in the pump line. Pump the well after calibration to flush out any possible contamination.

9. Using the zero knob on the recorder, adjust the recorder pen to the measured depth.

The cable will stretch for about 3 months after installation. Recalibrate the system monthly until it stabilizes. After the three month period of adjustment, the system need only be re-calibrated quarterly.

Recorder*

The characteristics of the recorders used are as follows:

Power:	12 VDC unit functions from an internal "sealed" lead acid battery and is charged from a built-in charger. The charger is operated from 115/230 VAC ±10%, 50/60/400 Hz.
Wattage:	1 Hz @10 cm/min 5 watts, trend line @1 cm/hr 0.15 watts.
Writing Method:	Pens are disposable fiber tipped units with self-contained ink supply.
Chart Width:	100mm calibrated, 0-100 divisions (overall width 120mm or approximately 4.72 inch).
Dimensions:	Height 6.25" (15.63 cm); width 8.75" (21.88 cm); depth 11.5" (28.75 cm).
Weight:	11 pounds (5.0 Kg).
Span:	1mV, 10mV, 100mV, 1 volt, and 10 volts ± 10:1 variable attenuator (full scale).
Input:	Floating (±100V single ended).
Input Impedance:	2.5 meg ohm fixed, all ranges.
Pen Response:	Less than 0.5 second, full scale.
Damping:	Critically damped on all ranges (requires no adjustment).
Accuracy:	Deadband ±0.1%. Linearity ±0.5%. Repeatability ±0.1%
Zero Adjust:	Continuously adjustable from -100% to +100% (full scale + 100% suppression) on each range. Left hand zero is standard.
Chart Speeds:	10 speed metric - 0.5, 1, 2, 5, 10 cm/min. 0.5, 1, 2, 5, 10 cm/hr.

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*Recorder characteristics are furnished courtesy of Linear Instruments Corp.

It was necessary to modify three of the recorders so they would operate on the twelve volt, DC power, supplied by the windmill-battery system. The power circuit modification is shown in figure 13.

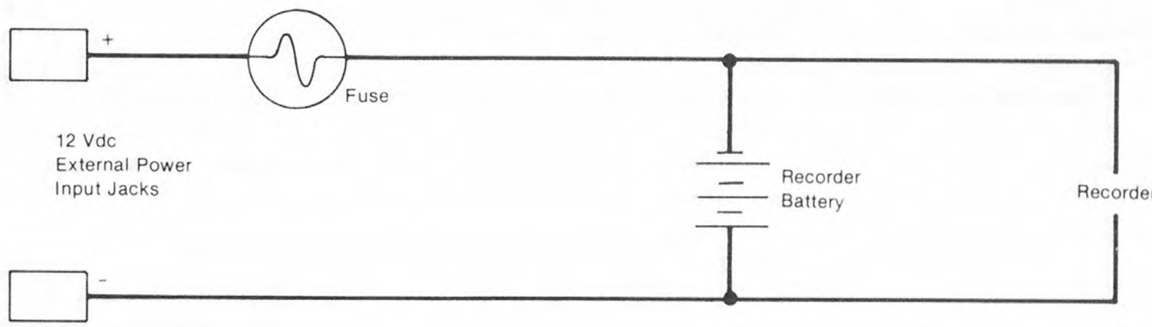

Figure 13.--Recorder circuit modification.

Desiccator

In order to prevent natural condensation or dust from plugging the surface vent tube of the transducer cable, a desiccator (fig. 12) was installed. The desiccant used is $CaCl_2$. When the desiccant is dry it is blue, but when it is saturated with water it turns purple or red. To reuse the dessicant, dry it at about 250° F until it turns blue again. A 7-micron filter was installed on the desiccator air intake to filter out dust.

Windmill *

For good performance, the wind-driven generator must be mounted where the wind from all directons has an uninterrupted flow to the propeller (fig. 5). Obstructions such as trees, hills, or buildings, even if they are somewhat lower than the windmill, will set up air turbulence that reduces the generator output. The windmill should be mounted at least 15 feet above any obstructions within 400 feet.

The wind-driven generator should be mounted as close to the batteries as possible. The farther it is mounted from the batteries, the greater the loss of energy in the wires. Number 10 stranded wire is heavy enough to connect the generator to the ammeter (fig. 12) when a power regulator is used. Wire of larger size may be necessary if a regulator is not used.

During the assembly of the windmills, it may be necessary to grind the brake shoes so that they will fit properly inside the brake drum. For greater safety, install a pull chain extension on the brake rod. This allows the windmill operator to stop the windmill before climbing the tower for maintenance.

*The windmill mounting information is furnished courtesy of WINCO, a division of Dyna Technology, Inc.

Batteries

Storage batteries are 12 volt heavy-duty marine type. Marine batteries were chosen because they can be recharged from zero to 12 volts, 400 to 500 times. Five batteries connected in parallel (fig. 12) were used per recording system. The system can operate with only three batteries during warm weather.

It is very important to not short circuit the battery terminals because of the large amount of electrical energy they contain. The arcing which results from such a short is very strong and dangerous. Do not allow sparks or fire near the batteries because they release explosive hydrogen gas while they are being charged.

Power Regulator

A power regulator is necessary to prevent overcharging and the resultant damage to the batteries. The windmill manufacturer has designed a circuit to regulate the voltage output of the generator, but due to the high winds at the INEL, we found that a voltage regulated power shunt (fig. 14) met our needs better than the manufacturer's circuit. This shunt system allows the batteries to charge as long as the windmill output voltage does not exceed 13.5 volts. When 13.5 volts is exceeded, the windmill power output is diverted to a heating coil where the energy is dissipated. The shunt regulator has kept our batteries fully charged. In areas with less wind, a different type of regulator, or perhaps none at all, may be required.

In very windy areas, failure to install a power regulator can harm the electrical system. Without a regulator, we damaged three batteries by overcharging while testing the windmill. If wind speeds exceed 60 miles per hour and there is no regulator, the reverse current diode (fig. 12) may

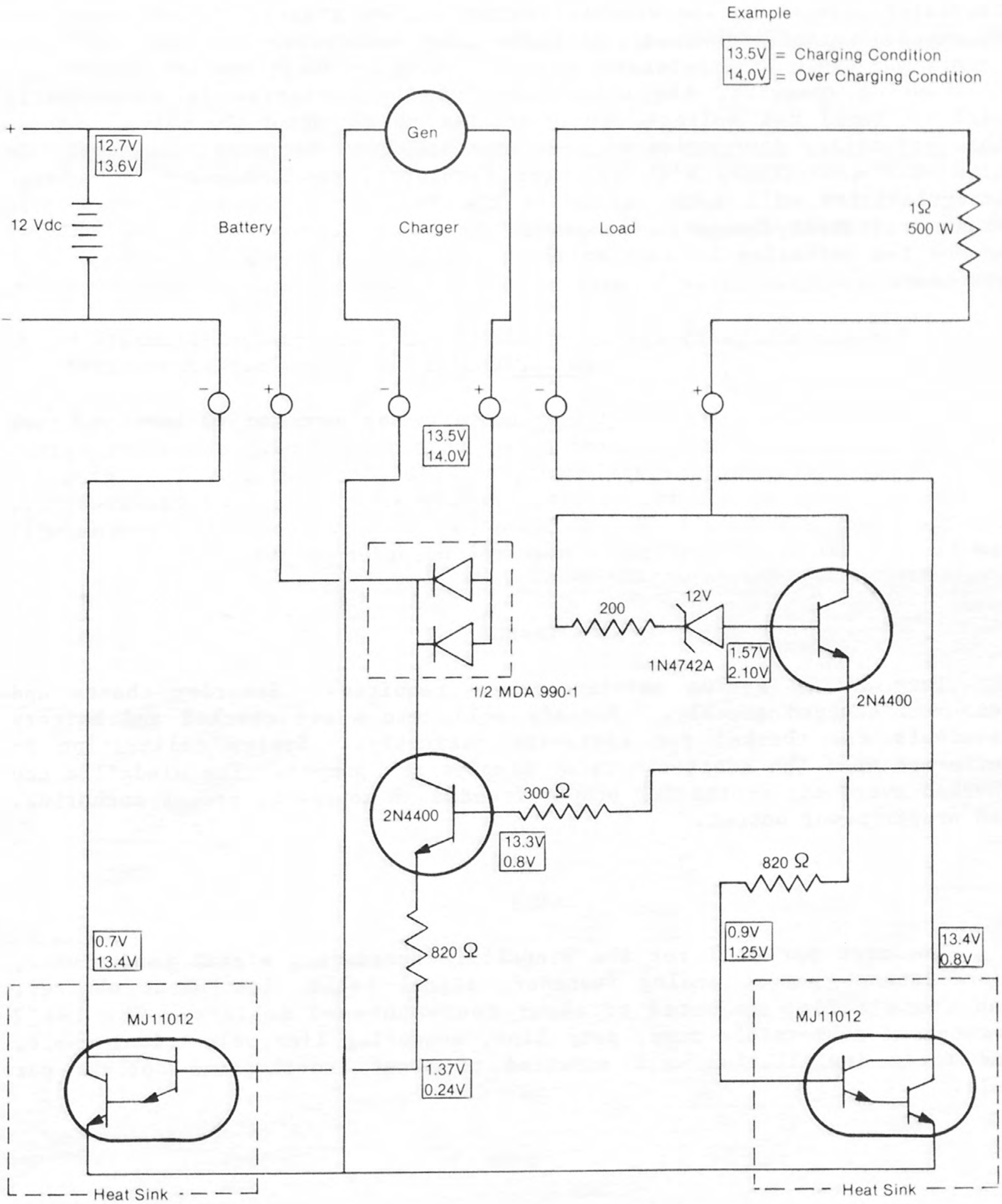

Figure 14.--Power regulator, shunt type.

burn up. The resistance of the regulator will sharply decrease the amperage put out by the generator in high winds. System tests without a regulator have shown the windmill output can be greater than 80 volts and 30 amperes during high wind conditions.

During charging, the capacitance of the batteries is sufficiently high to level out voltage irregularities up to about 20 volts. Above this potential, some noise will be seen in the power supply voltage. In high wind conditions, with no power regulator, the power supply voltage irregularities will cause noise in the transducer system and may even cause instrument damage. The power regulator limits the maximum voltage across the batteries to 13.5 volts and thus eliminates power supply noise problems.

Proper Grounding

The cable shielding must not contact any portion of the pressure transducer, the outer probe casing, or any other conductors on the probe end of the cable. At the well head, the cable shielding must be grounded to the well casing, the transducer, the signal conditioner, the recorder, and the power supply ground. Failure to properly ground the system will result in an induced noise pattern on the recorder output.

MAINTENANCE

Very little system maintenance is required. Recorder charts and pens are changed monthly. Battery acid levels are checked and battery terminals are checked for corrosion quarterly. System calibration is performed when the quarterly water samples are pumped. The windmills are checked every six months for proper freedom of movement, proper anchoring, and proper power output.

COST

The cost per well for the windmill, transducer, signal conditioner, miscellaneous parts, analog recorder, signal cable, instrument shelter, and installation amounted to about four-thousand dollars. The 1-1/2 horsepower submersible pump, pump line, measuring line, electrical cable, and their installation cost amounted to about two-thousand dollars per well.

SUMMARY AND CONCLUSION

1. The transducer-determined water-level measurement system is sensitive enough for our study purposes. System sensitivity is 0.01 foot $\pm$ 0.01 foot.

2. The system requires very little maintenance. Only one brief visit per month is required.

3. The well head is sealed, preventing contamination of the well.

4. A submersible pump provides for collection of water samples.

5. A windmill-battery power supply system is practical for remote instrumentation power.

6. The total system cost is not prohibitive.

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