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HYDROLOGIC TEST SYSTEM FOR FRACTURE FLOW STUDIES IN CRYSTALLINE ROCK

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Eileen

Hydrologic Test System For Fracture Flow Studies in Crystalline Rock

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ABSTRACT

A hydrologic test system has been designed to measure the intrinsic permeabilities of individual fractures in crystalline rock. This system is used to conduct constant pressure-declining flow rate and pressure pulse hydraulic tests. The system is composed of four distinct units: (1) The Packer System, (2) Injection System, (3) Collection System and (4) Electronic Data Acquisition System. The apparatus is built in modules so it can be easily transported and re-assembled. It is also designed to operate over a wide range of pressures (0-300 psig) and flow rates (0.2-1.0 gal/min). This system has proved extremely effective and versatile in its use at the Climax Facility, Nevada Test Site.

1.0 INTRODUCTION

The objective of this paper is to describe and document a hydrologic test system designed to measure intrinsic permeabilities of individual fractures in crystalline rock. This work was done as part of the site characterization for field radionuclide migration studies in granite at the Climax Stock, Nevada Test Site. Overall project objectives and technical approach are described in detail by Isherwood et al.[1]

The primary objective of these studies is to develop equipment and procedures for a reliable radionuclide field migration test that can be used at candidate repository sites in fractured rock. The experimental concept uses two boreholes drilled horizontally into the drift wall to intersect sets of vertical fractures at near right angles. The boreholes are located one above the other about 7 feet (2m) apart. The critical parts of the experiment are to successfully isolate an individual fracture between the boreholes and to establish flow along that fracture such that most of the fluid injected into the top borehole is recovered in the bottom borehole. Specific hydraulic tests can be used to determine the individual flow characteristics of a given fracture.

Previous studies of permeability measurements in fractured crystalline rock are present in the literature.[2-4] The significant feature of this system is that it can be easily transported and can operate over the wide range of pressures and flow rates which can be encountered in fractured rock. Furthermore, this system has the capability for establishing a circulating system from an upper borehole to a lower borehole along an individual fracture. This is accomplished by using inflatable straddle packer assemblies which are linked to a water injection-collection system. Intrinsic permeabilities can then be determined by conducting constant pressure-declining flow rate hydraulic tests or pressure pulse tests along individual fractures. An electronic data aquisition system allows a constant record over time of all parameters monitored.

2.0 EQUIPMENT DESIGN AND OPERATION

This design is based on very generalized criteria since the flow characteristics of a given fracture were not known beforehand. The necessary measurements include the flow rate of input water, flow rate of output water, input and output pressure in the straddled intervals and pressure in the zone behind the far packer. The system was designed to encompass a maximum range of pressures and flow rates. The maximum input pressure is 300 psia and the flow rate can vary from 0.2 gal/min (0.8 l/min) to 1 gal/min (3.7 l/min). The system is divided into four distinct units: (1) the Packer System, (2) Injection System, (3) Collection System and (4) Electronic Data Acquistion System. The functional interaction of these units can be seen in Figure 1. The entire system meets Lawrence Livermore National Laboratory design and safety standards.[5]

2.1 PHYSICAL ARRANGEMENT

The apparatus is built in modules which can be easily transported and lowered down the access shaft at the Climax Facility where they are re-assembled. The modular system, including gas bottles is mounted on a cart which has standard flanged railroad wheels to fit the existing rails in the drift.

The cart is made from high-strength welded aluminum plate with modular components bolted to the main frame plate. The physical system layout is shown in Figure 2. The rail cart is approximately 7' (2 m) long by 3' (0.9 m) wide by 6' (1.8 m) high. The gas bottles are nested horizontally in the main frame of the cart very low between the rails (low center of gravity for stability). Waste water collection bottles are located on the lower part of the cart in order to allow free gravity flow from the collection hole. The system is all manually controlled. All controls are mechanical and pressure gauges are provided for monitoring and data purposes. The system is independent of electrical power except for the electronic data acquisition module. Additional non-electric back-up measurement systems allow the experiment to continue even when the electronic module is not functioning.

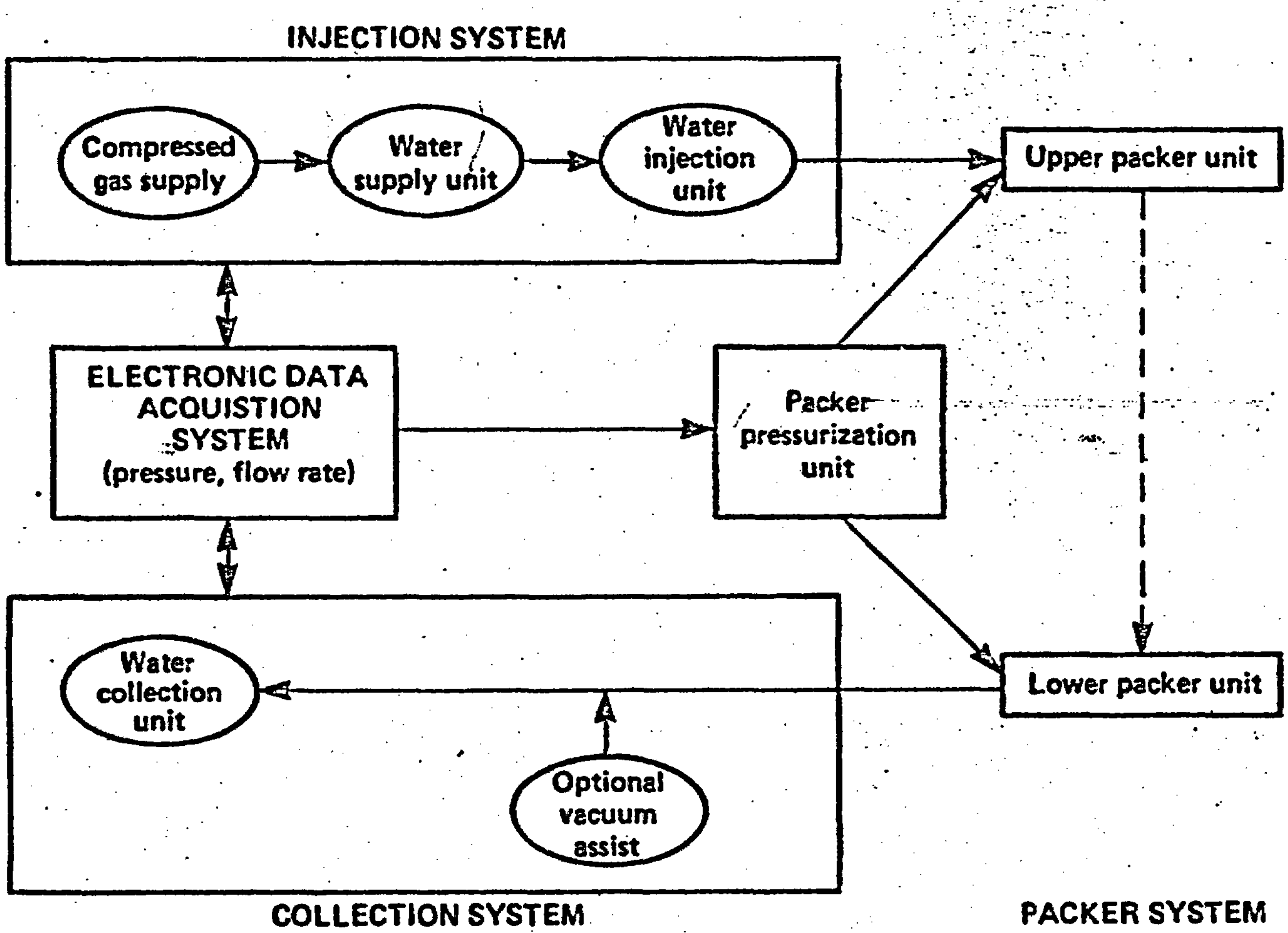

Figure 1. Functional Interaction of Equipment System

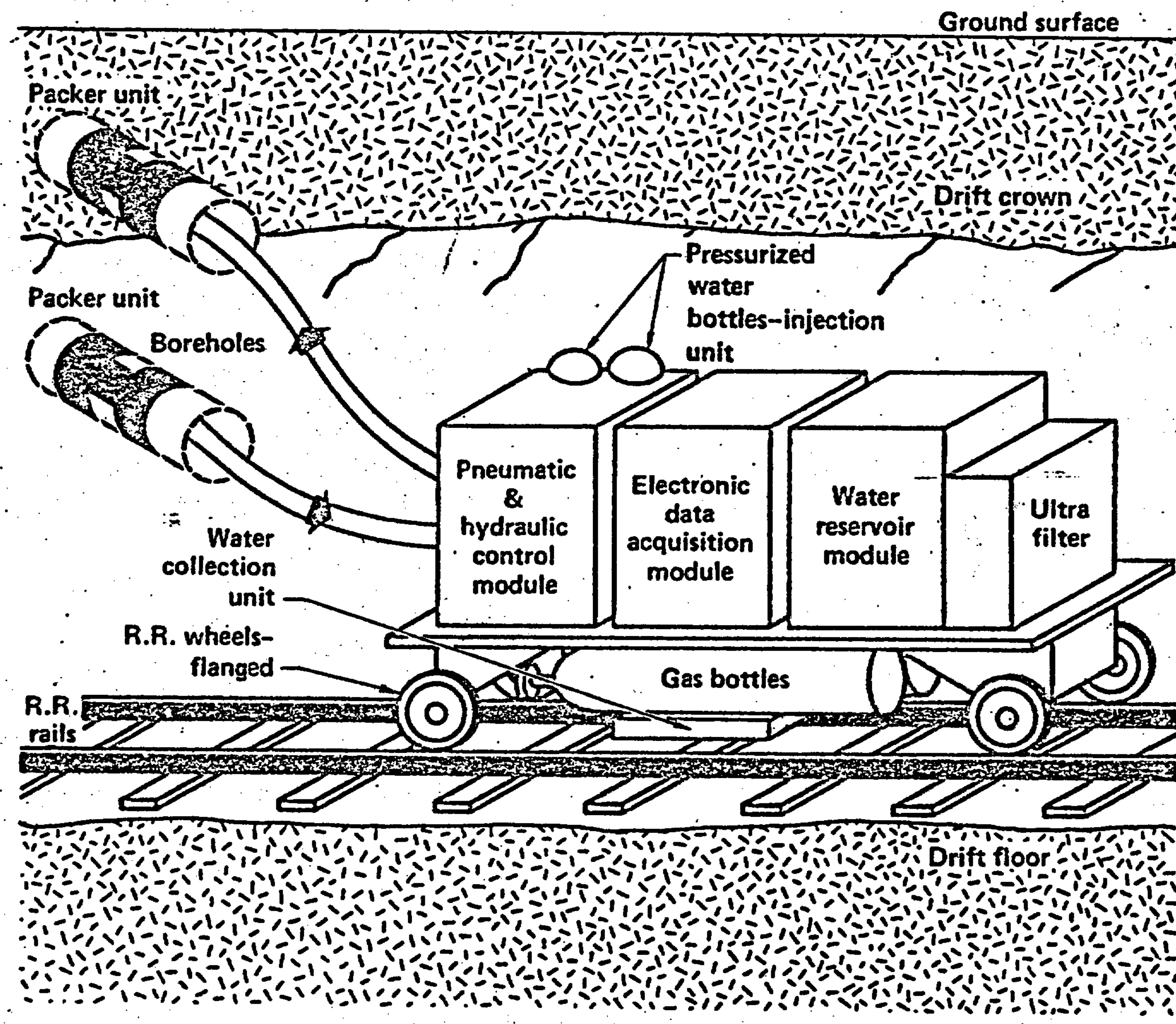

Figure 2. The Physical System

2.2 THE PACKER SYSTEM

The packer system includes a packer pressurization system and an upper and lower packer unit (Figure 1). The packer unit consists of a straddle packer with a center interval spacing that permits adequate isolation of a single fracture. Access transmission tubes were placed through the packer elements to permit monitoring of pressure changes in the packed off zone and the zone beyond the far packer.

The packer units are inserted into the boreholes and rubber bladders inflated tightly against the walls. Since the straddled intervals will be pressurized, the importance of the seals cannot be overemphasized from the standpoints of personnel safety and success of the experiments.

A variety of borehole packers are commercially available. However, only a few commercial companies could provide straddle packers for 3" (76 mm) NX boreholes which could be modified to permit pressure access lines as previously discussed. Two balloon-type inflation straddle packers with an 18" (0.46 m) fixed straddled interval were utilized in these experiments. These modified units can be seen in Figure 3. In the laboratory testing of these packer units, the amount of leakage past the sliding seals precluded using pneumatic inflation. The leakage was reduced, although not eliminated, by prefilling the packers with water and using gas over hydraulics as the pressurizing medium. The equipment design, therefore, utilizes hydraulic actuation of the packer for minimum leakage by using the system shown in Figure 4 although the option for pneumatic operation is present. The capability for independent inflation of top and bottom packer exists, although normal operations could utilize dual inflation. The system allows restrained packer pressurization up to 400 psig.

2.3 INJECTION SYSTEM

The water supply may be either transported to the site in a transfer drum or obtained locally. The water used in the experiment is transferred through an ultrafilter into the system reservoir, a 55 gallon polyethylene container (Figure 5). This insures removal of suspended particulates down to < 0.002 m and should minimize problems associated with injectivity and fracture

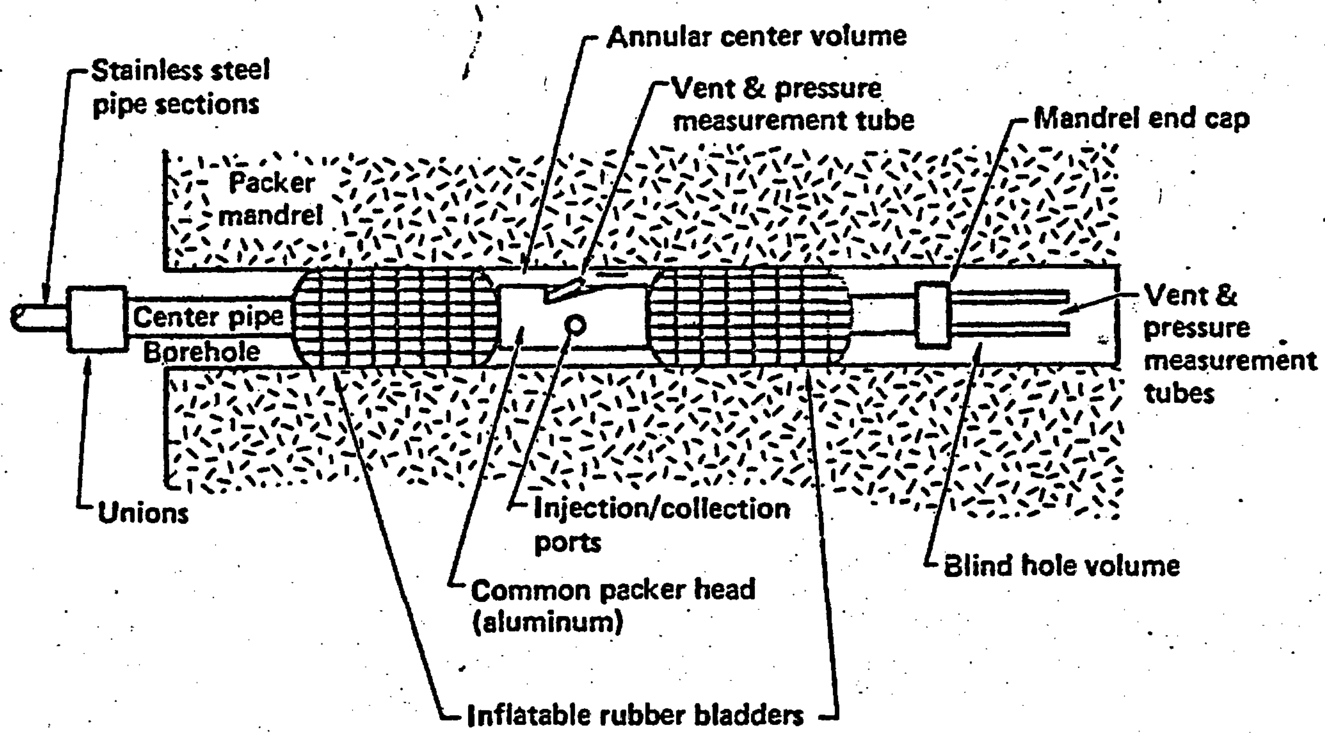

Figure 3. The Balloon-type Straddle Packer Unit. This is an artistic rendition showing the upper straddle packer unit with the vent tube in the 12 o'clock position.

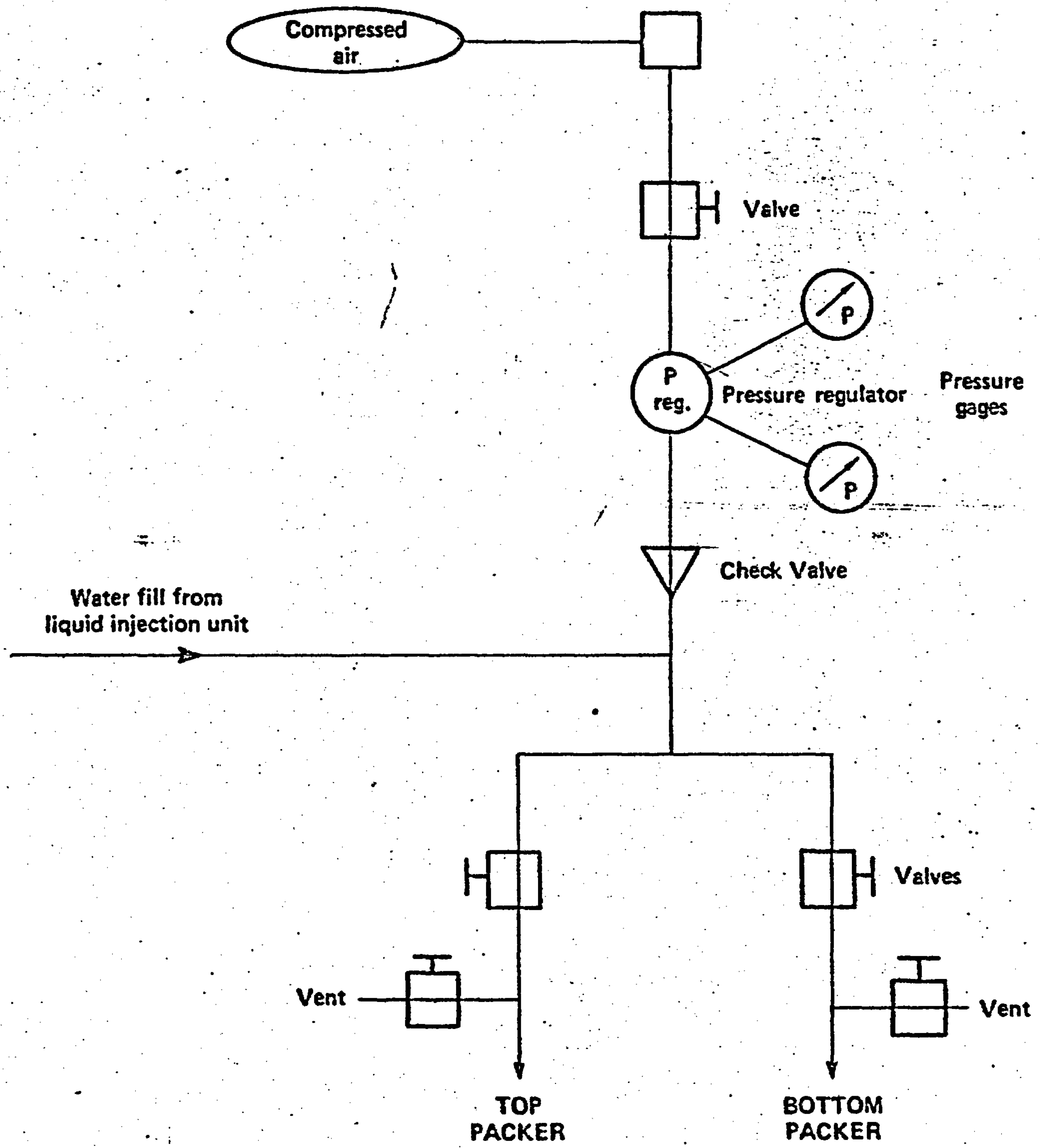

Figure 4. Packer Pressurization Unit

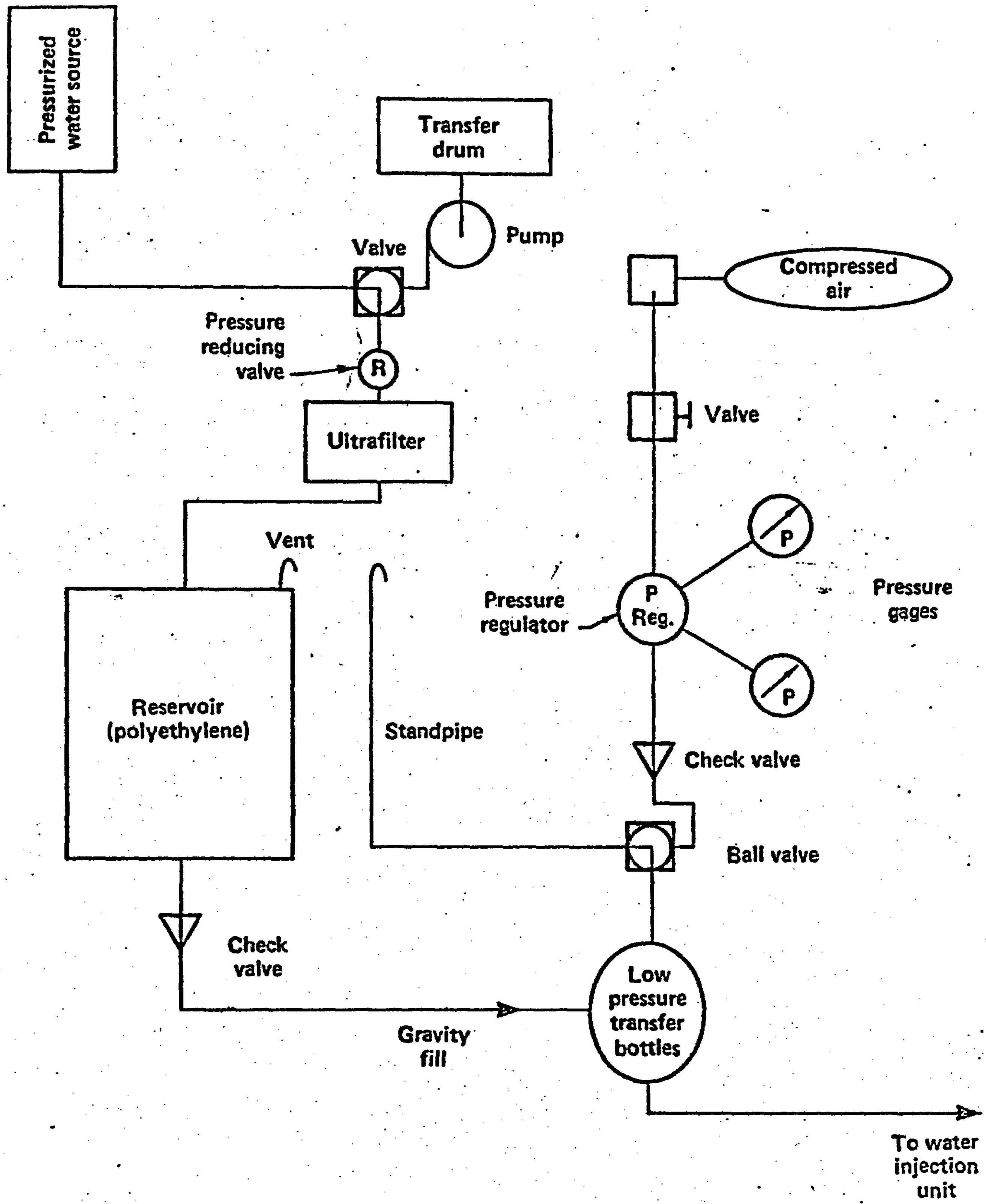

Figure 5. Water Supply Unit

plugging. Water flows from the reservoir through a check valve by gravity into low pressure transfer bottles located directly below. This low pressure system, 20-30 psig, is used for liquid filling the high pressure water injection unit.

The water injection unit shown in Figure 6 uses mechanical linkages between high pressure vessels allowing on-line or fill operations. After the high pressure vessels are filled, the mechanically-linked valves are switched into the off position allowing the low pressure air to vent from the transfer bottles, and to refill them by gravity from the 55-gallon reservoir.

The system for filling each pressure vessel is separate, thereby allowing one vessel to be on line for high pressure injection while the other is being filled. This system allows changeovers from an almost empty high pressure vessel to a full high pressure vessel without interrupting the flow. The high pressure vessels can be pressurized up to 300 psig for constant injection into the packer straddled interval. A pressure pulse input capability is also available. Injection pressure and time parameters are measured with strain gauge and quartz transducers via packer access transmission lines and are recorded digitally by thermal printers.

The primary input flow rate measurement is accomplished by a continuous weight measurement with respect to time of the high pressure vessels as they are emptied. This is done with load cells and the results are digitally recorded along with time by thermal printers. A secondary flow measurement is also available by reading the system injection and center volume pressures on a 12" Heise gauge.

Table I summarizes the measurement requirements for the complete system. Calibration of pressure transducers and load cells was done by the LLNL Calibration Laboratory using NBS derived standards. The use of Bourdon gauges for gas bottles and regulated pressure is standard practice. The pressure transducers and the load cells were chosen for reasons of remote sensing, stability and availability.

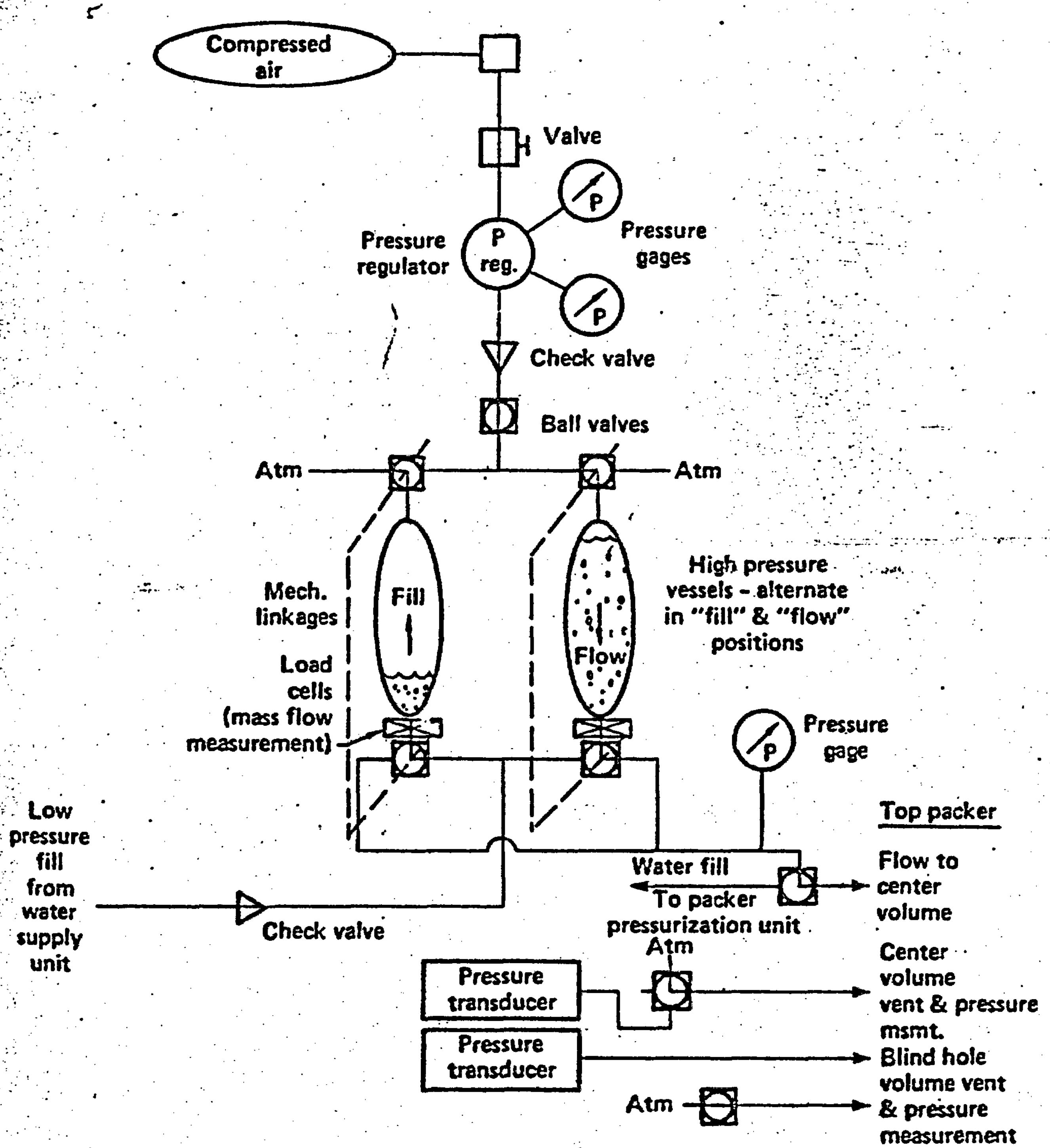

Figure 6. Water Injection Unit

Table 1
TOTAL SYSTEM MEASUREMENT CAPABILITIES

Location	Measurement Function	Type of Transducer	Range	Accuracy
Gas Bottles	Pressure	Bourdon Gauge	0-4000 PSIG	1%
Regulators	Pressure	Bourdon Gauge	0-1000 PSIG	1%
	Pressure	Bourdon Gauge	0-100 PSIG	1%
Injection Vessels Load Cells	Force	Strain Gauge	0-50 Lbs.	0.25%
Collection Vessel Load Cell	Force	Strain Gauge	0-10 Lbs.	0.25%
Upper Packed-off Volumes	Pressure	Quartz Gauge	0-500 PSIG	0.005%
Lower Packed-off Volumes	Pressure	Strain Gauge	0-50 PSIG	0.25%
Secondary Injection Measurement	Pressure	Bourdon Gauge	0-500 PSIA	0.1%

2.4 COLLECTION SYSTEM

Figure 7 shows the schematic for the collection system. The injection and collection systems are tied together by the natural fracture. Figure 8 shows the general schematic for all four systems. The collection packer unit is identical to the injection packer with one significant difference. The collection packer annulus or center cavity is maintained at atmospheric pressure. Since there is no internal pressure to contain, the task of sealing the lower borehole is somewhat easier. The blind-hole volume behind the packer unit is monitored for pressure build-up (leaks from the packer seals or a fracture interconnected with the injection hole).

This system has the capability to collect water either by gravity flow or with vacuum assistance. The output flow rate measurement is accomplished in a manner similar to the input measurement. The collected water is weighed by a

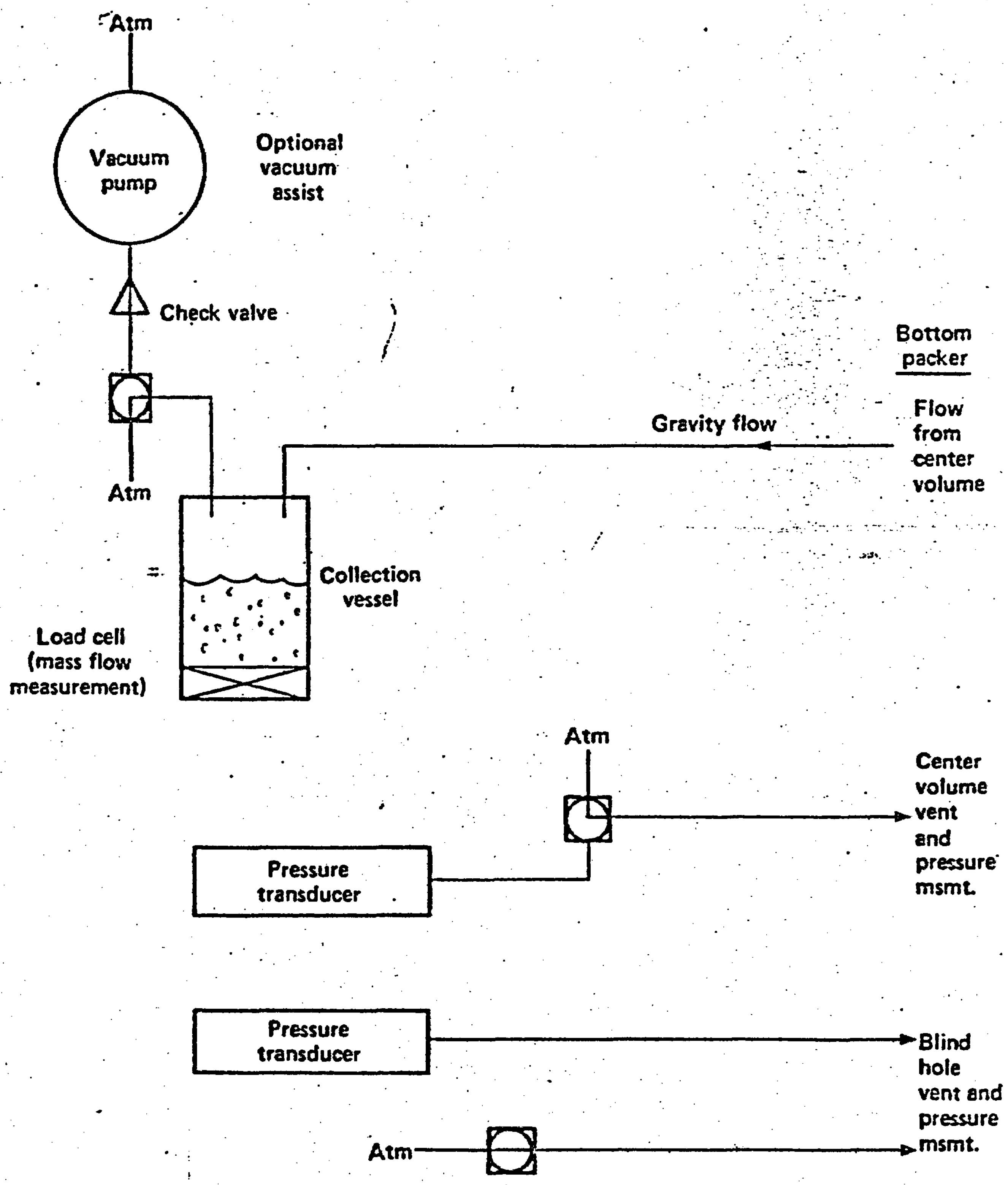

Figure 7. Collection System

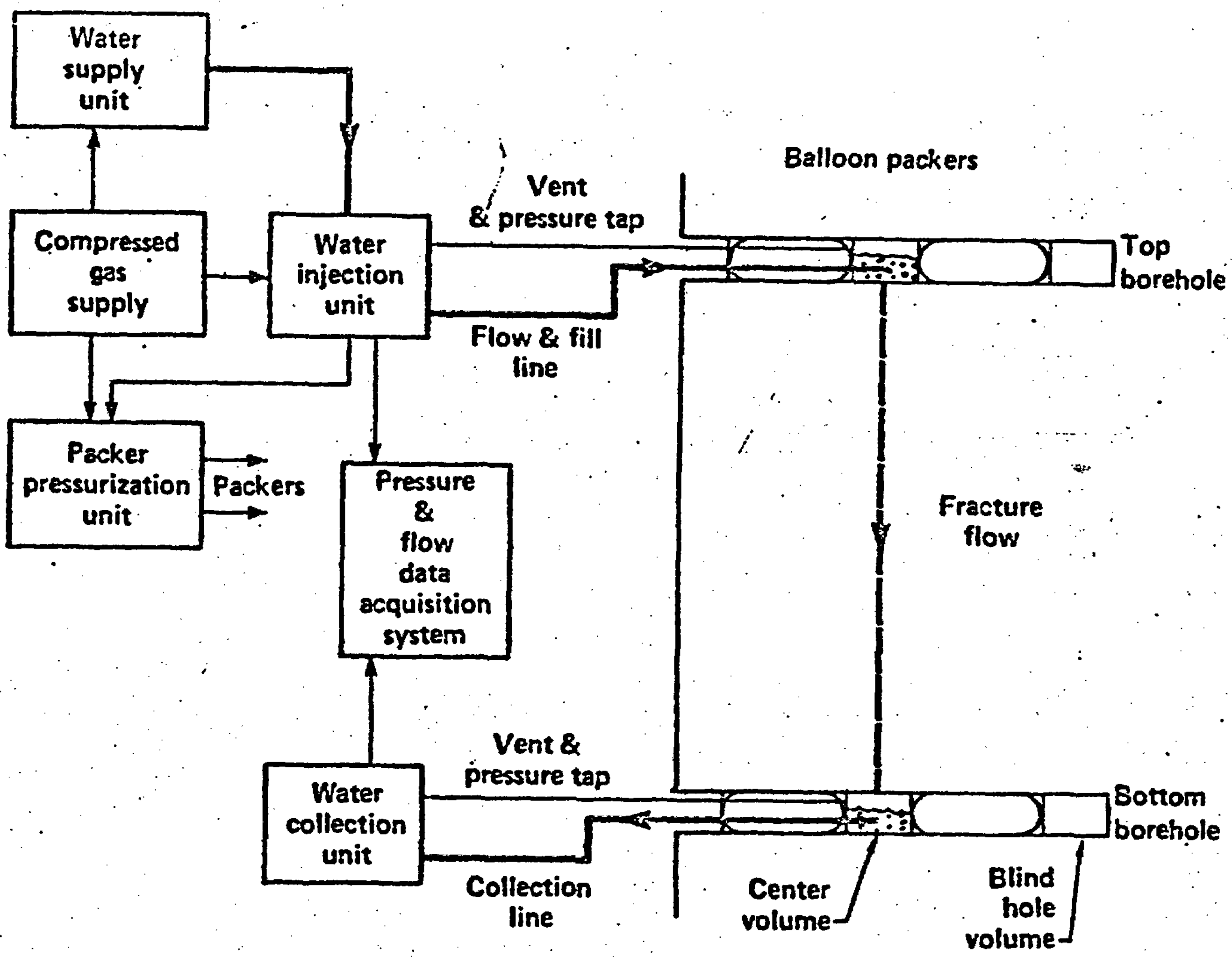

Figure 8. Injection-Collection System Schematic

load cell whose measurement is recorded digitally with time. A back-up flow rate measurement is also possible by timing level changes in the collection bottle. Table I lists the measurement cababilities of the collection system. All measurements are recorded digitally with time by corresponding thermal printers.

3.0 FIELD OPERATIONS AND TESTING

3.1 LABORATORY TESTING

The entire system including packer units was tested at LLNL using the borehole simulator shown in Figure 9. This consisted of two ten foot lengths of seamless meachnical tubing with threaded end caps. Two metering valves simulated the series, parallel flow impedance of the fracture. A fast response pressure transducer and associated recorder monitored the input volume response to input control changes. A mechanical engineering safety note documented that these tests met LLNL safety standards.[6] The equipment was then shipped to the Climax Facility, Nevada Test Site.

3.2 FIELD OPERATIONS

The first task is to locate a potential fracture connecting the upper and lower boreholes. This is done by visual logging with a high resolution borescope. The borescope has scribed divisions along its length to identify the fracture location and allow subsequent correct placement of the straddle packers.

The next step is emplacement of the top packer and saturation of the fracture. Both upper and lower straddle packer units are prefilled with water before emplacement. The upper packer vent tube is at the 12 o'clock position to allow fast filling and air escape. Once emplaced, the upper packer is then inflated to 300 psig using gas over hydraulics as the pressurizing medium.

The water supply unit is then hooked up to the mine supply water which was delivered at 80 psig. The water was routed through a pressure reducing valve to accomodate the pressure restrictions on the ultrafilter unit. After the 55-gallon water supply reservoir is filled, the operator is ready to start the injection tests.

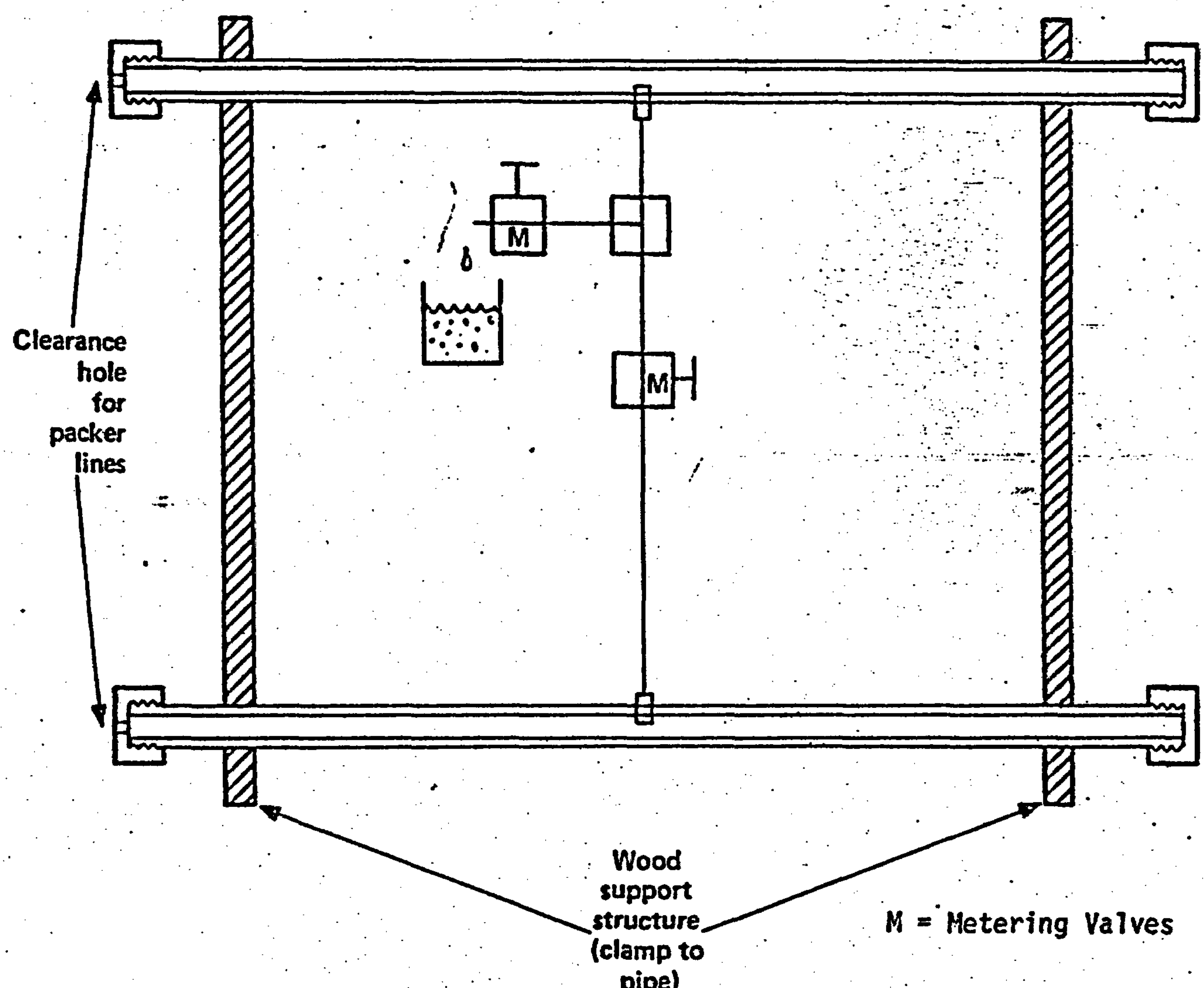

Figure 9. Borehole Simulator for Laboratory Testing

As stated previously, operations are controlled manually from the pneumatic and hydraulic control module panel. A series of valves control the application of pressure to the packer pressurization and injection systems. These systems are protected from over pressurization by appropriate relief valves. When the interconnecting fracture in the bottom borehole is identified visually using the borescope to determine which fracture is dripping water, the bottom packer assembly is installed to establish a circulating flow system between the two boreholes. The collection packer is placed in the lower borehole such that the collection tube is in the 6 o'clock position to enable water collection as soon as it enters the straddled interval. When the water reaches the bottom packer it flows through the drain lines and is recovered in the collection bottle. In some cases, we were able to establish a circulating system with up to 95% of the injected water being recovered.

The particular fracture characteristics can then be analyzed from flow and pressure data. Constant pressure - declining flow rate hydrologic tests were conducted in those fractures with high recovery rates. Results of these hydrologic tests are explained in detail by D. Isherwood et al.[7]

3.3 SYSTEM PROBLEMS AND IMPROVEMENTS

To improve the general operating characteristics of the system some changes should be made. The mechanical linkage between the high pressure vessels and the low pressure transfer bottles should be automated to make the changeover from one pressure vessel to the other. This would allow unattended operation of the system.

Additional problems were encountered with the water supply unit, although most were minor and could be overcome with repairs done in the field. The gravity feed of water to the low pressure transfer bottles was too slow in many cases. Employing a larger I.D. line should eliminate this problem (from 1/4" to 3/8"). Overpressurization of the polyethylene bottles caused seams on the bottles to split on several occasions. The bottles were field repaired by welding them with a oxy-acetylene torch. By employing larger lines and limiting pressure on bottles to 10 psig these problems can be avoided.

In general, we found this system to be extremely easy to operate and very effective for the various fracture characteristics encountered.

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