ORNL/TM-5545

Shale Fracturing Injections at Oak Ridge National Laboratory— 1975 Series

H. O. Weeren

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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AUGUST 1976

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SUMMARY

Intermediate level waste solution generated at ORNL is periodically mixed with a cement base blend of dry solids and injected into an impermeable shale formation at an approximate depth of 800 ft. Shortly after the injection the grout mix sets, permanently fixing the radionuclides in the shale formation. A series of three injections of intermediate level waste solution was made in 1975. A total of 190,000 gal of waste solution containing 86,700 Ci of radionuclides was injected. This report is an account of this injection series - preparations, injections, and results, and conclusions. A summary of the volumes and activities that were injected is given below:

Injection	Date	Vol of Waste (gal)	Vol of Water (gal)	Vol of Grout (gal)	Activity (Ci)
ILW-12	1-14-75	25,710	4,390	42,100	14,076
ILW-13	4-29-75	81,000	4,900	126,100	39,118
ILW-14	6-20-75	82,970	9,500	138,700	33,466
		189,680	18,790	306,900	86,660

After the 1972 injection series had been completed, several modifications were made to the injection facility. Ventilation and shielding were improved, a new mix tub was installed, additional aerators were installed on the storage bins, and the process instrumentation was modified. In June 1974, a site proof injection was made to verify the suitability of a nearby site for possible future waste disposal operations. The existing facility was used in this test injection to mix the grout that was to be injected; the installed facility modifications were thereby tested under near normal operating conditions and some deficiencies were noted and corrected. Also, at this time the dry solids mix was modified by the substitution of a different cesium fixer (pottery clay) for the previously used Grundite (which was no longer available).

Injection ILW-12 was scheduled for October 1974, and preliminary preparations had almost been completed when the injection date was delayed. At this time all of the solids to be used in the injection had been blended and stored. Preparations for the injection were resumed after a three month interval, and the suitability of the stored solids was questioned. Some nonconclusive tests were made that indicated that some deterioration in flowability had occurred, but there was no certain indication that the solids were unusable. In the absence of any real operating

data on long stored solids, the decision was reached to attempt the injection with the old solids. The injection went very poorly; the solids would not flow out of one storage bin at all and flowed very erratically out of the others. This difficulty with solids flow caused great difficulty with mix control and resulted in very irregular operation of the injection pump. This was probably a major cause of a series of minor malfunctions that resulted. A total of 25,700 gal of waste and 4400 gal of water was injected before the futility of continuing the injection under such conditions was acknowledged and the injection was ended. This somewhat abortive injection points up the importance to the process of having solids that flow easily without clumping, sticking, and bridging.

Injection ILW-13 was made on April 29, 1975. The injection went quite smoothly overall, but there were several minor difficulties. Failure of an air slide connection and plugging of a pump drain pan caused temporary shutdowns; and there was occasional difficulty with cement bridging in the mixer bowl, particularly after any slowdown or shutdown of the injection. A total of 81,000 gal of waste solution and 4,900 gal of water was injected at an overall solids to liquid mix ratio of 6.3 lbs/gal.

Injection ILW-14 was started on June 18, 1975. After two hours and twenty minutes of operation, the injection was halted because the waste pumps were not delivering sufficient pressure. The pumps were inspected and adjusted and the injection was resumed. The injection was continued for an additional two hours and forty-five minutes; at that time the packing of one of the pistons of the injection pump failed, allowing waste grout to leak past the piston into the pump cell. The injection was halted and the standby pump was used to pump the well clear of grout. The piping and mix tub were washed and cleanup operations were started to permit entry into the pump cell for repairs.

The injection pump was repacked on June 19; on June 20, the injection was restarted. Difficulty with the injection pump transmission prevented operation in the higher gears, and the remainder of the injection was made at an average waste flow rate of about 110 gal/min (180 gal/min is a normal flow rate). The remaining solids were mixed with approximately 42,000 gal of waste solution and 5700 gal of water (overall solids to liquid mix ratio of 5.66 lb/gal). This part of the injection was uneventful and was terminated after about seven hours and twenty minutes when the solids were consumed.

The control of the mix ratio was more erratic in this injection than it had been in previous injections, primarily because of unreliable mass meter readings. The accuracy of these readings is routinely checked against the known weight of solids in the storage bins as each bin runs empty - four times during an injection. In this injection this frequency was not sufficient and a large mass meter bias went undetected for several hours. A more frequent check can be made by estimating the consumption of solids from the ratio of slurry volume to solution volume and comparing this estimate with the mass meter readings. This procedure should be followed in future injections.

The cased observation wells were logged after the completion of Injection ILW-14. Two of these wells were found to have been plugged during this injection series and are probably unusable in the future. A third well was ruptured during the injection series, but is still usable. The pattern of grout sheets that is indicated by the logging results is similar to the pattern indicated by the previous injection series - grout sheets that are generally conformable to the bedding but to the northwest of the injection well are 20 to 30 ft higher than elsewhere.

Suggested improvements to the shale fracturing facility include improvements to the mixing tub viewing system, a change in the solids blending procedure, some instrument modifications, and some method of breaking the solids buildup that periodically occurs in the mixer hopper.

1.0 INTRODUCTION

The shale fracturing process has been used for the routine disposal of intermediate level waste solution at Oak Ridge National Laboratory since 1966. In this process the waste solution is mixed with cement and other additives; then the resulting mixture, or grout, is injected into an impermeable shale formation at a depth of 700 to 1000 ft - well below that at which groundwater is encountered. The injected grout forms a thin, approximately horizontal, sheet several hundred feet wide during the course of the injection. Shortly after completion of the injection the grout sets, thereby permanently fixing the radioactive wastes in the shale formation. Subsequent injections form sheets that are approximately parallel to the preceding sheets.

The most recent series of injections was made in 1972.[1] After this injection series had been completed, several modifications were made to the injection facility. Ventilation and shielding were improved, a new mix tub was installed, new aerators were installed on the storage bins, and the process instrumentation was modified. The shale fracturing facility has subsequently been used for a site proof test injection and three injections of concentrated intermediate level waste (ILW). The site proof injection has been described in a previous report.[2] This report describes the preparations for the ILW injections, summarizes each injection, discusses the data obtained from each injection, and presents the results and conclusions from the series as a whole.

2.0 DESCRIPTION OF PROCESS AND PLANT

2.1 General Description

In the shale fracturing process an alkaline waste solution is mixed with a solids blend composed of cement and other additives and then injected, under pressure, into a bedded shale formation at a depth of between 700 and 1000 ft. The pressure of the injected grout is sufficiently high to initiate the formation of a crack between adjacent layers of shale. As the injection continues, the grout fills this crack and extends it further to form a thin, approximately horizontal sheet several hundred feet in extent during the course of an injection. Figure 1 shows an isometric view of the shale fracturing facility.

Three types of wells have been used at the shale fracturing facility: an injection well for the injection of waste grout, observation wells for the determination of the orientation of the grout sheet, and rock cover monitoring wells for verification of the continued impermeability of the shale above the grout sheets. A sketch of each well type is given in Fig. 2. All waste injections are made through slots cut in the casing and surrounding cement of the injection well. As the grout sheet spreads out from the injection well, it intersects the cemented casing of one or more observation wells. A gamma sensitive probe in the observation well will then detect the presence of the grout sheet, thereby establishing the depth of the grout sheet at that point. The rock cover monitoring wells are used to periodically determine the permeability of the shale cover rock at a depth of 600 ft.

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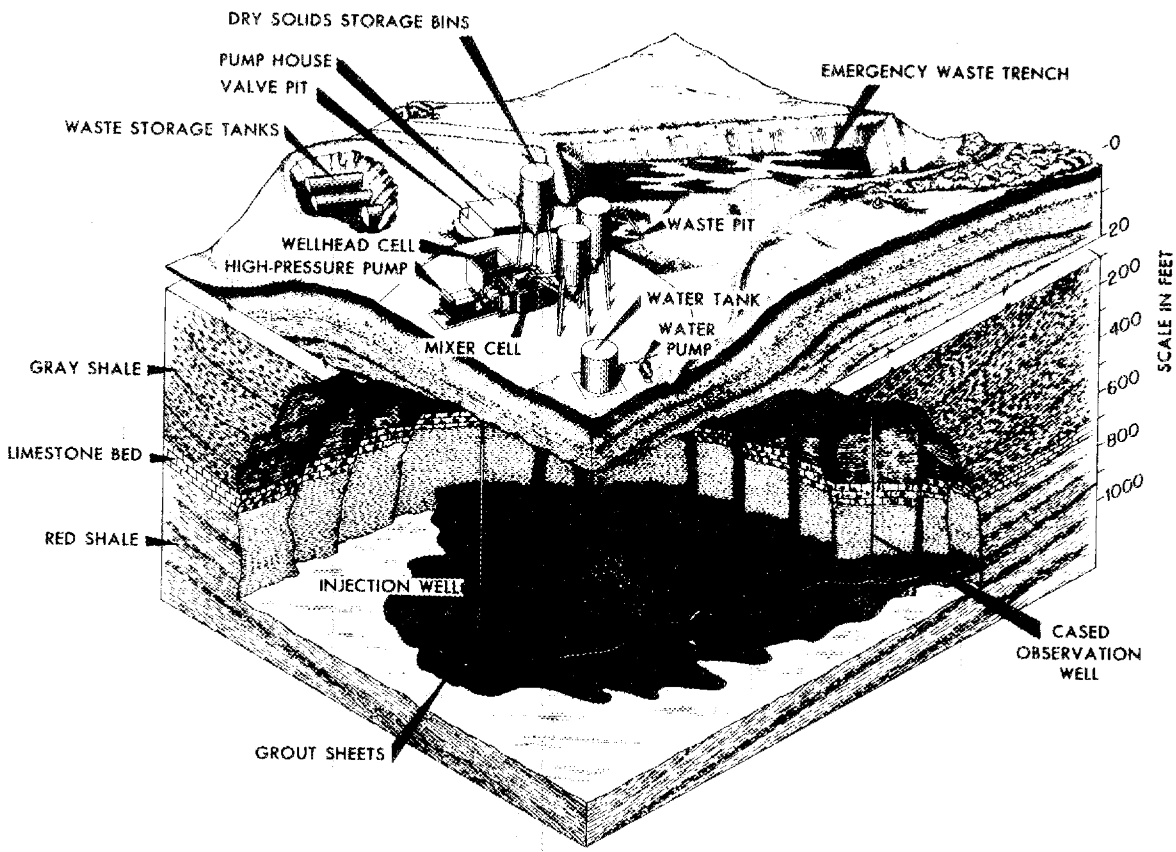

Fig. 1. ORNL Shale Fracturing Disposal Plant

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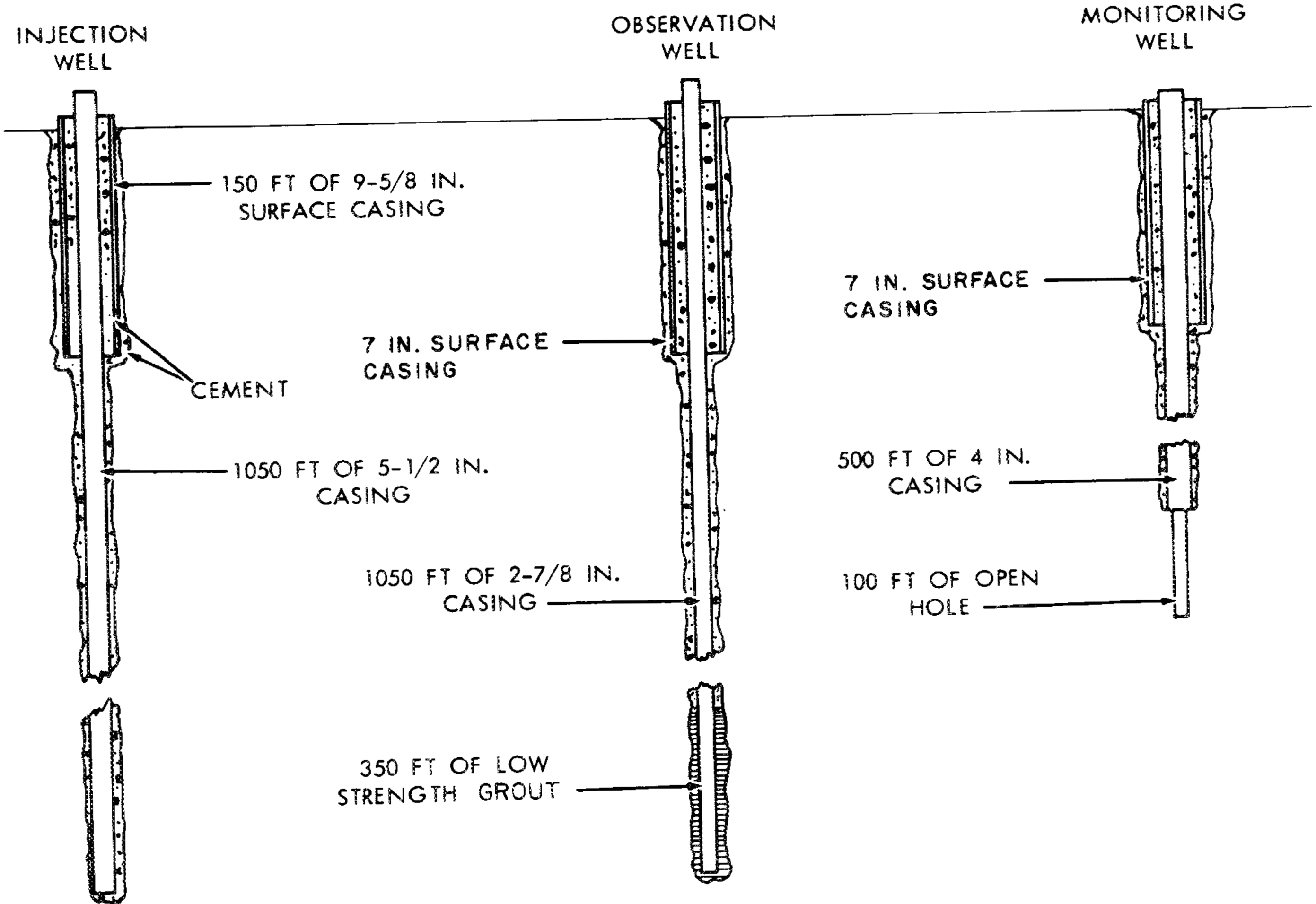

Fig. 2. Sketch of Wells for Fracturing Facility

The major process equipment used to inject a batch of waste consists of a waste pump, a jet mixer, a surge tank, and a high-pressure injection pump; a flow diagram is shown in Fig. 3. Preblended solids are stored in bulk storage bins for use as needed. A standby injection pump is always available to clear the injection well in the event of failure of the main injection pump. During an injection, waste solution is pumped to the mixer, continuously mixed with the preblended solids, and discharged into the surge tank. From the surge tank the grout is pumped down a tube hung in the injection well and out into the shale formation.

Five underground waste storage tanks, with a total capacity of 90,000 gal, are installed at the shale fracturing plant. Prior to each injection, the waste solution is pumped to the site through a waste transfer line at a rate of approximately 20 gpm and stored in these tanks.

A week or more before an injection, the solids - cement, fly ash, Attaplugus 150 (a water retaining clay), a clay for cesium retention, and a retarder - are brought to the fracturing site, blended in the desired proportions in a weigh tank, mixed by blowing them back and forth between two pressure tanks (P-tanks), and stored in four bulk storage bins. These bins (capacity, 2780 ft^3 each) are 12 ft in diameter and installed on legs so that their bottoms are approximately 6 ft above the top of the mixing cell. During an injection, the solids in each bin in turn are aerated and flow through an air slide (an enclosed chute that is continuously aerated from below) into a metering hopper in the mixing cell and, from there, into the mixer.

The jet mixer is a device for mixing the waste solution and the solids. As the waste solution is pumped through the mixer under pressure (100 psi), the solids drop into the mixer and are then picked up by the jet stream and thoroughly mixed with the waste. The resulting grout is continuously discharged into the surge tank. The mixer bowl is connected to the hopper to confine the solids and any grout that might splash out of the mixer. For convenience, an observation window is provided.

The surge tank furnishes a means by which the flow of the waste transfer pump and the flow of the injection pump may be synchronized during an injection. One operator, who controls both pumps, observes the level of grout in the surge tank, either through a mirror and window arrangement

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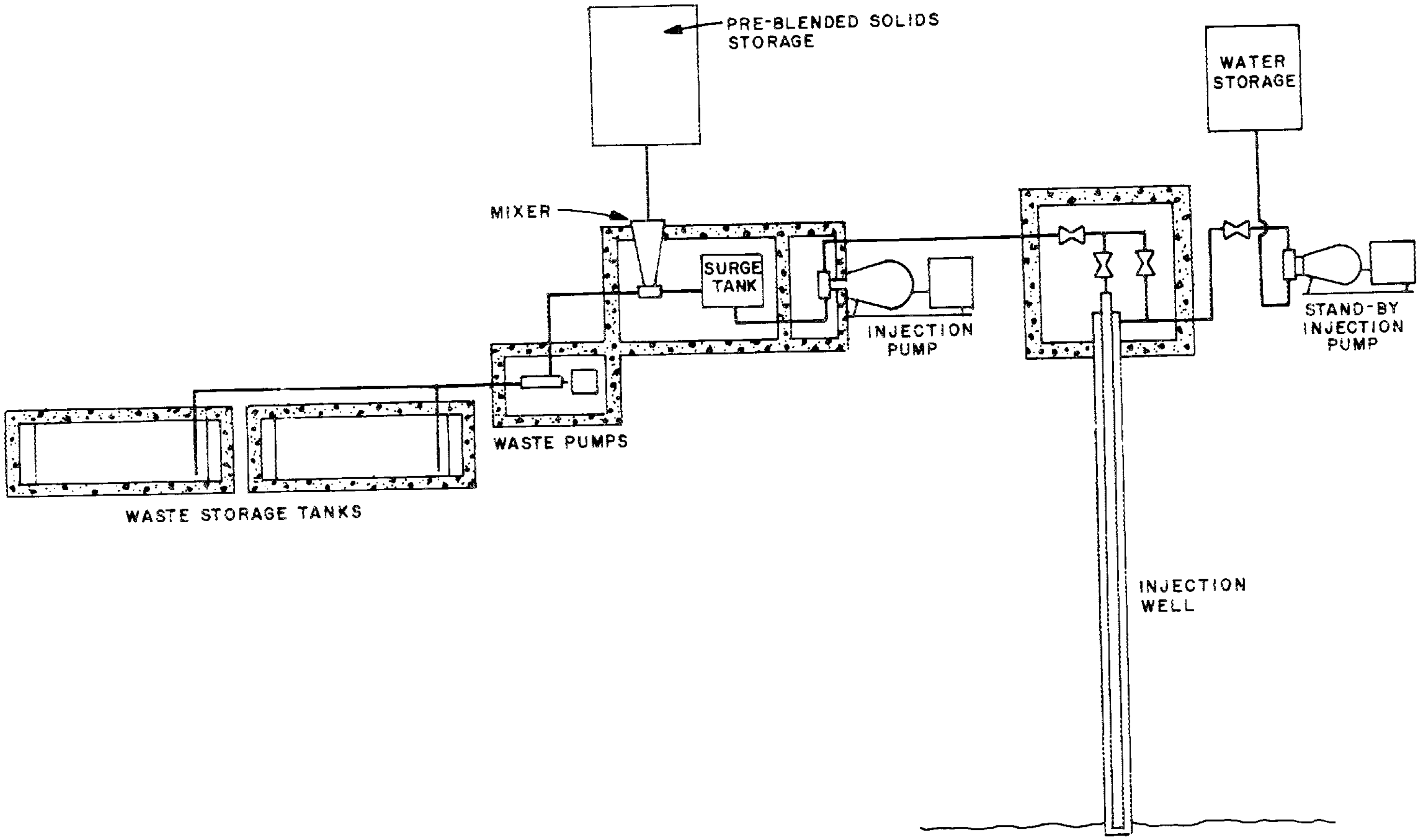

Fig. 3. Flow Diagram of Shale Fracturing Facility

on top of the tank or by observing a float-type level gage. He adjusts the flow rate of one or the other of the pumps as the grout level fluctuates. During an injection, air is withdrawn continuously from the surge tank, filtered through a high-efficiency filter, and discharged.

The control of the proportions at which solids and waste solution are mixed in the fracturing plant is critical. If the proportion of solids is too high, the resulting grout will be viscous, difficult to pump, and subject to premature setting. If the proportion of solids is too low, the grout will fail to retain all of the associated liquid and will exhibit "phase separation" on setting. This is undesirable because some small fraction of the radionuclides (much less than 1%) will remain with the water and thus will not be immobilized. The desirable operating range between these two extremes is fairly narrow; the variation from the desired proportion should not exceed 10% at most and should be kept within 5% if possible. During a waste injection this mix ratio is controlled by manually regulating the flow of solids from the metering hopper to maintain a fixed ratio of solids addition for a given waste flow rate. The solids addition rate is measured by a mass flowmeter, a device that continuously weighs the flow of solids, installed immediately below the metering hopper. In the first eleven operational injections, a check on the solids proportioning was provided by the Densometer system. (The Densometer is a device that continuously measures the density of the fluid circulating through it.) A small hydraulic pump mounted in the surge tank continuously pumped grout from the surge tank, through one of two Densometers, and back to the surge tank. These instruments were difficult to maintain and were not consistently reliable. They were removed after Injection ILW-11.

Three cells are provided for the mixing and injecting equipment - one for the mixer and surge tank, one for the head end of the injection pump, and one for the wellhead and associated piping. All cells are made of a 12-in. thickness of concrete block and are roofed with a 3/4 in. grating covered with sheet metal. The cells are painted but unlined. The roof of the mixer cell is fixed in place; the roofs of the pump cell and wellhead cell are removable. Because the process piping in the pump cell and the wellhead are under considerable pressure during an injection (up to 5000 psi), the vision ports in these cells are made of bullet-proof glass and the roof grating is covered with 1/4 in. steel plate on both sides. Access may be gained to the cells through a hatch in the roof of each.

The injection pump* is capable of pumping over a range of pressures and flow rates between 6000 psi and 105 gpm, and 1000 psi and 700 gpm. A steel splash plate is fitted around the head of the pump and extends to the walls, floor, and roof of the cell, thereby isolating the pump head within the cell.

A standby injection pump** similar to the main injection pump, is rented for each waste injection. During each injection it is connected, via the wellhead manifold, to the injection well. Its function is to provide a means for flushing the injection well free of grout in the event that the main injection pump fails. This pump is not required to pump radioactive fluids.

A piping manifold connects the injection pump, the injection well, the standby injection pump, and the waste pit. This manifold contains 10 plug valves, 2 check valves, a pressure relief valve (set at 6000 psi), a pressure gage connection, and 13 unions. The components of the manifold are rated at 10,000 psi or more. Extra high-pressure Chiksan swivel joints are used between the injection pump and the piping manifold, and between the piping manifold and the wellhead, to damp vibration between the pumps and the wellhead.

A considerable volume of water is required for such operations as slotting the casing of the injection well and washing equipment after an injection. Since this water will become contaminated, it must ultimately be injected with the waste solution. To keep the contaminated water from constituting a large fraction of the waste being injected, it is necessary to reuse water where feasible. The waste pit, a concrete pit 12 x 12 x 9 ft deep, was built to serve this function. Washup water and water that is used in slotting operations drain to the waste pit and are pumped out of the pit by the waste pump for reuse.

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*A Halliburton HT-400 triplex positive-displacement pump.

**A standard truck-mounted Halliburton positive-displacement pump.

An emergency waste trench is provided as a precaution against the unlikely possibility that, late in the course of a waste injection, the wellhead might rupture and allow the injected grout to flow back up the well. Should such an event occur, the grout would flow from the wellhead cell through an 18 in. line to the 100,000 gal waste trench where it would set and be covered with earth fill.

A cell off-gas system removes 2100 cfm of air from the mixer cell, pump cell, and wellhead cell, through a roughing and a high-efficiency filter in series, and exhausts it out a short stack. A separate off-gas system provided for the surge tank exhausts through a demister mounted above the tank and a high-efficiency filter, and then discharges the air to the suction side of the cell off-gas filters.

Necessary information on the progress of an injection is obtained from readings of the waste tanks levels, the waste flow rate, the grout flow rate, the solids flow rate, and the injection pressure. The orientation of the grout sheet is determined after the injection is completed by logging the various observation wells.

Small volumes of free water can be formed in the disposal zone by phase separation of the injected grout. This phase-separated water contains only a small fraction of the radionuclides that have been injected (much less than 1%), but it is thought desirable to remove these relatively mobile radionuclides from the formation. This is done after each injection or series of injections. The wellhead shutoff valve is opened and any free water that may exist is bled back through the injection well and collected. Ultimately, this recovered water is pumped back to the waste collection system in Bethel Valley.

The development of the shale fracturing process is described in Ref. 3; Reference 4 is the safety analysis of the process.

2.2 Recent Facility Modifications

A number of generally unrelated improvements were made to the shale fracturing facility after the 1972 series of injections. The purpose of these modifications was to reduce the radiation exposure accumulated during operation and maintenance, improve ventilation, and improve the control of the process.

The rectangular mixing tub (surge tank) was replaced by a new stainless steel tub with a circular cross section that could be more easily cleaned and decontaminated. The new tub is 36 in. in diameter and has a maximum operating capacity of 146 gal (187 gal in the old tub). Auxiliary equipment includes a viewing window on top of the tub, a 1/4 hp agitator, a float-type level indicator, and a 3/4 in. expanded metal screen that is fitted across the tub near the grout inlet nozzle. The Densometer pump that had been installed in the old surge tank was not required in the new tank because the Densometers had been removed from the system.

Shielding was provided around the injection pump head and the suction hoses in the injection pump cell to reduce the radiation exposure during maintenance operations.

Shielding was provided for the top of the mixer cell to reduce the radiation exposure during wash-up operations at the end of an injection and to permit occasional maintenance operations during an injection. The radiation field on top of the mixer cell during an injection had been 1 to 2 R/hr; this was reduced by approximately a factor of 10 in those areas requiring access.

A chain hoist and support frame was provided above the solids feed hopper so that the accumulating hopper and attached mass flow meter could be lifted above the mixer cell roof for maintenance and calibration.

The ventilation system for the five waste storage tanks was modified by the addition of an exhaust fan and a second HEPA filter in series with the present filters. Ventilation was provided for the building housing the waste pumps. The existing ventilation capacity of the system serving the mixing, wellhead, and pump cells was increased and the off-gas ventilation from the mixing tub was improved and its capacity increased.

The inside surfaces of one of the four solids storage bins (Bin 2) were painted to provide a smoother surface to improve solids flow characteristics.

The air distributors in the solids storage bins were renovated to provide better flow characteristics along the walls of the bins.

A new valve control was installed on the solids flow control valve so that automatic operation of this valve could be attempted.

The existing turbine flowmeter in the waste line to the jet mixer was relocated in a valve pit adjacent to the waste pump house. A strainer with approximately a 1/8 in. mesh screen was installed upstream of this flowmeter to remove scale that might jam the flowmeter. In series with the turbine flowmeter, a second flowmeter (orifice type) was installed to provide a backup indication of the waste flow rate.

Instrumentation to measure the level of solids in the solids storage bins and a continuous recording viscometer to be installed on the mixing tub were ordered but were not installed until after the Site Proof Test (see Section 3.2).

2.3 Recommendations of the Pressure Review Committee

A 1973 review of the operations of the Shale Fracturing Facility by the ORNL High Pressure Review Committee resulted in several recommended changes to equipment or operating procedures. In response to these recommendations, the piping swivel joints were anchored to the floor of the well cell so that these piping assemblies would be restrained in the event of a piping rupture, the pressure relief valve setting was lowered to 6000 psi, and a "declutching" device was installed on the injection pump. The function of this declutcher was to limit pressure at the wellhead to a maximum of 5500 psi, even during momentary pressure surges. The declutcher accomplishes this function by throwing the injection pump out of gear whenever an excessive pressure is sensed. Alternate methods of accomplishing this function (such as stopping the diesel drive of the pump or valving off the wellhead) could not be done quickly enough to prevent the wellhead pressure from exceeding the desired limit.

3.0 RESULTS OF SITE PROOF INJECTION AND PREPARATION FOR INJECTION SERIES

3.1 Site Proof Injection

A site proof injection was made in June 1974 to test the suitability of the formations underlying a nearby site for possible future waste disposal by shale fracturing.[2] The existing Shale Fracturing Facility was used in this test injection to mix the grout that was to be injected; the mixed grout was then pumped to the site of the new injection well through an overland line. Since the volume of grout that was pumped in this test injection was approximately equal to that pumped in a waste injection, the site proof test was a rigorous test of at least some of those facility modifications that had been installed at this time.

Immediately after the injection was started, the flow of solids to the mixer became uncontrollable and the mixer cone was quickly jammed with solids. The injection was promptly shut down so that the excess solids could be cleared and the cause of the difficulty determined. It was found that the controls to the solids master valve had been installed backwards so that the valve was opening instead of closing and vice versa. The controls were reversed and the mixer cone and mass meter were cleared of solids.

The injection was resumed and ran well. There was one brief shutdown to clean the window of the surge tank, which had been covered on the inside with grout splashed from below. The injection was restarted without difficulty. As is usually the case, the control of the mix ratio became much more difficult as each solids storage bin ran empty and the solids flow became erratic.

Prior to the site proof injection the solids storage bins had been cleaned, one of the bins had been painted, and new air pads had been installed on the bins. The flow of solids was much improved in this injection, but it is not obvious which change in the system (if any) contributed most to the improvement. The new air pads were used when two of the bins were being emptied and were not used when a different two bins were being emptied; no particular difference was noted. Solids flow from Bin 2 (the painted bin) was quite smooth the first time the bin was emptied and less smooth the second time (after the solids stored in the blending tanks had been emptied into it); the effect of painting the bin is not apparent. Smoother solids flow was observed when Bin 1 and Bin 2 (the first time) was being emptied. These bins contained the solids blends with a relatively high fly ash content; the fly ash content of the solids stored in the other bins was about 15% less.

3.2 Facility Modifications

Some of the planned facility improvements (instruments with long delivery times) had not been installed at the time of the site proof injection. These instruments were installed between the time of the site proof injection and the time of the next waste injection. In addition, some further modifications that were suggested by difficulties with the site proof injection were made at this time.

During the site proof injection, the grout that was discharged into the mixing tub struck the top of the screen and splashed upward against the vision port at the top of the tub. To reduce or eliminate such splashing, the screen was relocated to a position just above the suction intakes to the injection pump. In addition, air and water nozzles were installed inside the tub so that the inside of the vision port could be washed during an injection.

A Dynatrol viscosity measuring instrument* was installed in the mixing tub. This instrument measures the resistance the slurry offers to the movement of a vibrating rod. This resistance is a measure of the slurry "viscosity" at a fixed rate of shear. Since the slurry "viscosity" varies directly with the solids to liquid mix ratio, it was believed that the instrument readings would be a measure of the mix ratio and that, after suitable calibration, this instrument could be used to either control the mix ratio or provide a useful check on the readings obtained from the mass meter.

Devices were installed to measure the level of solids in the storage bins. Three strain gages were installed, each on one leg of Bins 1, 3, and 4. These gages measured the strain on the leg and, therefore, the weight of solids in each of the bins. In Bin 2, two Metritapes** were installed. These devices are tapes that extend from the top of the bin to the bottom or near the bottom. The pressure exerted by solids in the bin squeezes the tape and alters its electrical resistance. This electrical resistance is therefore a measure of the level of solids in the bin. Metritape #1 was installed about 2 ft from the side of the bin and extends to the bottom cone; Metritape #2 was installed in the center of the bin and extends to within 4 ft of the bottom.

*Automation Products, Inc., Model CL-10DV-4, Houston, Texas.

**Metritape, Inc., West Concord, Massachusetts.

3.3 Mix Modifications

The solids mix used in all waste injections through ILW-11 contained 7.7% by weight of Grundite (an illitic clay). This constituent was included in the mix as a cesium absorbent; the cesium atoms in the waste were bound to the structure of the illite and retained in the grout when the mix set. In 1974, the supplier of Grundite discontinued operations and a new mix additive was required to replace the now unavailable Grundite in future waste injections.

Screening tests were made with several possible Grundite substitutes to select those additives with good cesium binding ability and without adverse effects on the physical characteristics of the mix. Ground Conasauga shale was found to be the best of the tested additives. Mixes made with this additive retained cesium much better than did the Grundite and had physical characteristics similar to the Grundite mixes. Grinding and drying equipment for this shale were not immediately available, however, and a clay with cesium retention somewhat inferior to Conasauga shale (but superior to Grundite) was selected because of its availability in bulk. Amaco Pottery clay (Indian Red) was found to retain cesium better than Grundite and to have no adverse effects on grout properties. A mix containing 2.4 wt % pottery clay was found to retain cesium approximately as well as a mix containing 7.7 wt % Grundite.[5] A mix containing about 2.9% pottery clay was used in all subsequent waste injections.

4.0 INJECTION ILW-12

Injection ILW-12 was planned for the week of October 7, 1974. Preliminary preparations for this injection included the pumping of 88,000 gal of ILW concentrate to the waste tanks at the shale fracture site, the blending of 584,000 lbs of dry solids, and miscellaneous maintenance operations. On October 4, the injection was postponed indefinitely, pending receipt of final clearance from ERDA. Clearance for an injection was received in January 1975, and the injection was made on January 24.

4.1 Preliminary Preparations

4.1.1 Waste Transfer and Analysis

Waste solution was pumped to the five waste storage tanks at the shale fracture site during August and September. This waste came from two different Gunite tanks (W-8 and W-10) and was distributed among the tanks at the shale fracture site as shown in Table 1.

Table 1. Waste Solution Volumes for Injection ILW-12

Tank	Solution	Volume (gal)
T-1	W-10	14,179
T-2	W-8	14,179
T-3	W-10	23,872
T-4	W-10	23,872
T-9	W-8 and W-10	12,322

Composite samples of the waste solutions were obtained during the transfer; analyses of these solutions are given in Table 2.

Table 2. Analyses of Waste Solutions

Ion	Waste W-8	Waste W-10
NH_4^+ gm mol/ℓ	<0.003	0.06
OH^- gm mol/ℓ	0.17	0.04
NO_3^- gm mol/ℓ	1.69	1.05
SO_4^{-2} gm mol/ℓ	0.125	0.114
Cl^- gm mol/ℓ	0.24	0.18
CO_3^{-2} gm mol/ℓ	0.335	0.22
Al^{+3} gm mol/ℓ	0.028	0.012
Na^+ gm mol/ℓ	2.39	1.48
Cr mg/ml	–	0.011
Si mg/ml	none	0.007
ρ gm/ml	1.1396	1.0937
^{137}Cs Ci/gal	0.47	0.496
^{134}Cs Ci/gal	0.0047	0.0037
^{106}Ru Ci/gal	0.0138	–
^{90}Sr Ci/gal	0.0146	0.0515
α Ci/gal	2.2×10^{-4} (99.7% ^{244}Cm)	0.001 (>99% ^{244}Cm)

4.1.2 Solids Blending

Five batches of dry solids were blended during the week of September 30 - October 4. Four batches were loaded in the storage bins and the final batch was left in the blending tanks for later transfer to an empty bin. The weights of the various ingredients that were used for the solids mix are given in Table 3.

Table 3. Dry Solids Mix for Injection ILW-12

	Bin 1	Bin 2	Bin 3	Bin 4	P Tanks
Cement, lbs	47,907	47,910	48,080	49,040	48,240
Fly Ash, lbs	46,329	44,100	44,590	48,300	45,160
Attapulgite, lbs	19,700	20,360	19,310	19,010	19,330
Clay, lbs	3,370	3,360	3,290	3,200	3,680
Sugar, lbs	39	39	39	39	39
	117,345	115,759	115,309	119,589	116,449

The cement used was Signal Mountain, Type I. Since a sample of Type II cement obtained from this supplier in 1964 had flash set, a recent sample was obtained and tested with synthetic waste. This sample did not flash set; grouts made from this cement behaved similarly to grouts made from Volunteer Type I cement tested earlier.

The sugar (delta glucone lactone) was in short supply at the time the solids were blended and, rather than postpone the blending operation and the subsequent injection, the concentration of sugar in the dry mix was reduced by 30%.

4.1.3 Tests of Mix Compatibility

Samples were taken of the blended dry solids from the top of each of the four storage bins and tested with water and synthetic waste solutions. Phase separation and rheological properties were determined for grouts made with various mix ratios. Most of the tests were made with grouts that were prepared by mixing the dry solids and waste solution at 5000 rpm (to simulate down-hole conditions), but some tests were made with grouts that had been mixed at 2000 rpm (to simulate tub conditions). The tests indicated that the phase separation of the grout in the formation would be less than 2% if the mix ratio were between 7 and 8 lbs of dry solids per gallon waste.

A mix ratio with water of between 8 and 9 lbs of dry solids per gallon of water would be required to keep phase separation low.

4.1.4 Plant Improvement and Maintenance

During the site proof injection test in June 1974, the mass meter had been inadvertently filled with cement. This cement was removed at that time by washing out the mass meter, but the readings of this instrument were biased during the subsequent injection. Prior to Injection ILW-12, this instrument was cleaned and recalibrated.

4.2 Holding Period - October to January

The injection was originally scheduled for October 9. On October 4, ORNL was told by the ERDA to delay the injection, pending final approval.

The waste solution stored in T-4 was pumped back to the ORNL tank farm. This was done so that an empty tank would be available at the shale fracture site to contain the contents of any tank that might develop a leak.

In Injection ILW-11 more difficulty than usual had been experienced in obtaining an even flow of solids from the storage bins and more solids than usual had been left in the bins at the end of the injection. Some of the solids used in this injection had been blended three weeks before the injection - about two weeks longer than usual. Several factors other than solids storage time could have been involved, but the observed association of longer than usual storage times with poor solids flowability raised some doubts of the usability of the solids stored at the shale fracturing site. Because of these doubts, samples of the solids were taken periodically and tested. Two types of tests were run. In one set of tests the solids were mixed with synthetic waste and the phase separation and rheological properties were determined. In the second set of tests a "flowability index" of the dry solids was calculated from the measurement of various characteristics of the dry solids - angle of repose, compressibility, cohesion, and angle of rupture. These tests are discussed in References 6 and 7. The tests with the mixed grout indicated a slight (and probably insignificant) increase in phase separation and decrease in grout viscosity with increased solids storage time. The tests with the dry solids indicated that the "flowability" of the solids was decreasing with time. Since the flowability index numbers for which the solids would be usable was not known, this measurement of the deterioration of flowability was not conclusive. On December 4, a truck load of solids (about 6000 lbs) was dropped from Bin 4 to test flowability. The solids flowed quite readily. A few small lumps were observed in the solids but these lumps were quite soft and easily crushed. It was concluded that the usability of the stored solids was questionable but there was not sufficient evidence that they were unusable to justify discarding them without a trial.

4.3 Resumed Preparations

4.3.1 Maintenance

Permission for the injection was received in January. Since it has been recommended by the Pressure Review Committee that, because of possible danger of low temperature embrittlement of the high pressure piping, no operations be undertaken at an operating temperature below 40°F, heaters were left in the pump and wellhead cells over the weekend prior to the injection and during the injection week. These heaters kept the cell temperature well above the 40° minimum during this time.

The injection pump was repacked.

The ball and seat of the pressure relief valve were replaced. After the slotting operation had been completed the valve was found to be leaking slightly. Another ball and seat were installed, and the valve was set to relieve at 6000 psi. The replaced seat was found to be eroded.

The device for declutching the injection pump at 5500 psi was adjusted and tested.

4.3.2 Slotting

The existing slot in the injection well at 832 ft was plugged with 250 gal of cement slurry on January 20. This slurry was displaced with 217 gal of water - sufficient to force the top of the cement plug to 827 ft. The well was shut in under pressure for 18 hrs.

Pressure was applied to the plug on January 21. The plug broke at 4000 psi. Water was pumped past the plug at 2300 psi and 160 gal/min. A second plug was set. This plug was 350 gal of cement slurry that was displaced with 217 gal of water.

On January 22, it was discovered that circulation through the well could not be achieved; that is, water could not be pumped down the tubing string and up the annulus. The tubing string was free in the well (it was not cemented to the bottom), but the level of cement in the 5-1/2 in. casing was found to be at 802 ft - at approximately the bottom of the tubing string and 25 ft higher than it should have been. The tubing string was logged and found to be plugged about 50 ft above the end of the string. It was ultimately concluded that the displacement volume for the second plug had been measured incorrectly and that the plug had not been pumped clear of the tubing string.

The tubing string was removed a length at a time from the injection well. The two bottom sections were found to be plugged with cement. The seating nipple was removed from the bottom of the tubing string and cleaned. The tubing string was reconnected and replaced in the well; the two plugged sections of tubing were discarded. To make up the tubing string to the required length, it was necessary to use three pup joints and one length of tubing (K-55) that had been procured for the site proof injection. These tubing sections have an 8-round thread and were installed between the crossover nipple and the wellhead flange. A 5 ft pup joint (with extreme line thread) was installed just above the seating nipple. All centralizers were replaced at approximately their previous locations.

The tubing sections that were removed from the well (and subsequently replaced in the well) read 100 to 400 mR at contact when wet, 1 R when dry; the α count was 5000 d/min. The bottom section of tubing (which was discarded) read 4 R at contact when wet.

The cement plug remaining in the well was eroded to a depth of 827 ft with a high pressure water jet, and the plug was tested at a pressure of 5000 psi. The well was slotted at 822 ft on January 23. The slotting pressure was about 3500 psi; the flow rate was about 130 gpm, and forty sacks of sand were used. The sand/water ratio was very nearly 1/2 lb/gal. The time required was about 1 hr. The formation fractured at a pressure of 4750 psi (measured at the annulus).

The rock cover monitoring wells were topped off with water; each well required 1 to 4 gallons. This job was a necessary preliminary to recording of the pressure readings of these wells during the injection.

4.4 Injection

The injection was begun at 1145 on January 24. Waste water was pumped from the pit to reopen the fracture. The formation re-fractured at 4700 psi (injection pump pressure gage); 430 gal of water were pumped into the formation. Cement flow was started, but virtually no flow from the bin could be obtained. Other bins were switched on stream, but very little cement was obtained from them. The injection was shut down at 1215 after 1300 gal of water and about 2000 lbs of cement had been mixed and injected.

The butterfly valves at the bottoms of the storage bins were examined. It was suspected that dry solids had packed behind the valves and prevented these valves from opening. At least some of the valves did appear to be jammed; these valves were freed. The injection was restarted at 1323, and at 1327 the flow was switched from pit water to waste (T-2). No appreciable flow of cement could be obtained from Bin 1 and the flow was quickly switched to Bin 2. The flow of solids was not smooth and the operation was, of necessity, rather spasmodic. The maximum attainable solids flow during parts of this period was only about 500 lbs/min. With a solids flow rate this low, a mix ratio of 7 to 8 lbs/gal could be maintained only by cutting the waste flow to 60 to 70 gal/min and the injection rate to 85 to 110 gal/min. These rates are below the operating minimum of the injection pump and could be handled only by stopping the pump, allowing the grout level in the surge tank to rise, restarting the pump, pumping the surge tank nearly empty, and repeating the cycle. This is a difficult way to operate. At 1355, a leaking head gasket on the injection pump forced a halt to the injection. During this period (32 min) 600 gal of pit water and 3200 gal of waste were mixed with 34,700 lbs of solids. The average waste flow rate was 119 gal/min and the average mix ratio was 9.1 lbs/gal.

The pump cell and the injection pump were washed to reduce the radiation exposure; and the head gasket on the pump was removed, examined, and replaced. In the course of the washup operations, the suction line of the injection pump was flushed with water. This wash water backed up into the mixer tub and, since the tub was not under observation at that time, filled the tub to overflowing. The overflow filled the mixer hopper and spilled into the mixer cell. Some of the overflow also got into the tub off-gas system.

When the situation was discovered, the wash water was shut off, the contents of the tub and mixer were drained to the waste pit, the off-gas filters were replaced, and the mixer hopper was washed to clean the window sufficiently for the solids level to be seen.

The injection was restarted at 1629 with waste solution from T-2 and solids from Bin 2. Operating conditions were similar to those noted previously - a low rate of solids flow that frequently required a stop and start operation of the injection pump. It was also noted that the solids were not feeding into the jet mixer as easily as they had in previous injections; they tended to build up in the mixer cone (at times they obscured the window), and the flow rate had to be reduced until the accumulation of solids could work its way out of the mixer hopper. At about 1815 the mass meter jammed (indicating 1500 lbs/min with no solids flow), and the injection was halted to clear this instrument. During this injection period (1 hr, 40 min), the average flow rate was 98.9 gal/min at a solids mix ratio of 6.9 lbs/gal.

The injection was resumed at 1836 and continued until 2055, when it was again halted to clear the mass meter. Waste flow was from T-2 and T-9; solids flow was from Bin 3 (very little), Bin 2, and Bin 4. No solids could be obtained from Bin 1. Solids flow was irregular, as was the case all during the injection. During this injection period (2 hr, 19 min), the average waste flow rate was 91.2 gal/min at a solids mix ratio of 5.5 lbs/gal.

The solids stored in the blending tanks were blown into Bin 2 and the injection was resumed at 2250. Waste flow was from T-1 and solids flow was from the refilled Bin 2. Solids flow was not improved and, as the run continued, the grout could be pumped from the mixing tub only with difficulty (it is probable that the screens in the tub were plugged). The injection was halted at 2315 to clean the screens in the mixer tub. At this time a leak in the high pressure manifold in the wellhead cell was discovered and the injection was terminated. The well was overflushed and shut in and the equipment was washed.

Plots of injection flow rate (totalizer readings) and injection pressure during the injection period are shown in Figs. 4 and 5. In previous injections, the flow rate had averaged a steady 180 to 200 gal/min; the

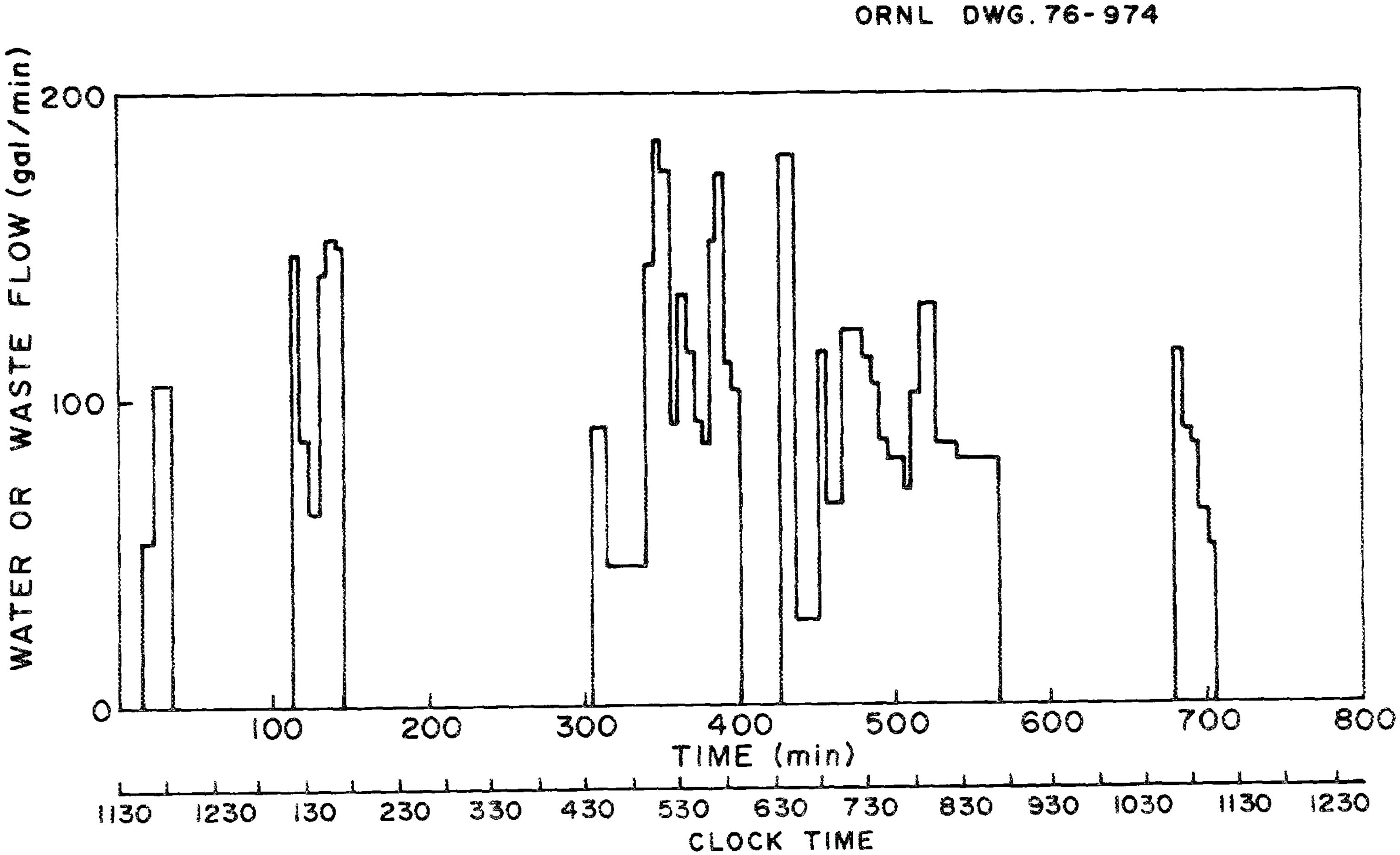

Fig. 4. Flow Rate During Injection ILW-12

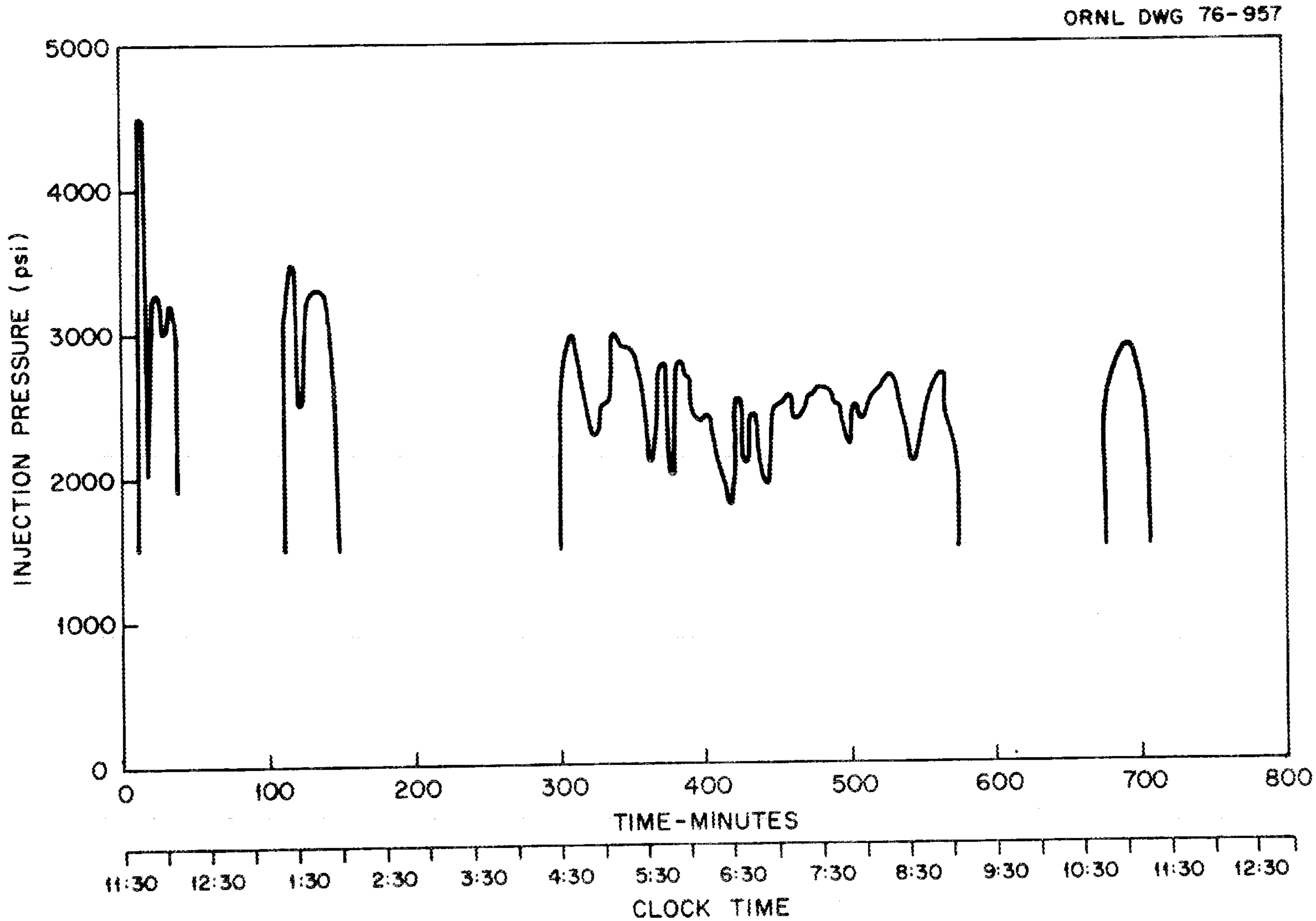

Fig. 5. Injection Pump Pressure During Injection ILW-12

contrast of this injection is striking. The injection pump pressure is quite irregular because of the spasmodic nature of the injection. It appears, however, that the injection pressure dropped rather quickly to about 2500 psi - approximately the injection pressure of ILW-11.

A plot of the viscosity readings obtained during the injection is shown in Fig. 6. This instrument was not calibrated prior to the injection, and the "viscosity" that the readings represent is not known. It is apparent, however, that the zero was set too high.

4.5 Data Analysis

Because of the erratic nature of the injection, many of the instrument readings were obviously in error at one time or another. The mass meter was reading very high and non-existent flows at least twice during the injection, and the indicated slurry flow rate was impossibly high at least twice; there were undoubtedly other less obvious errors. Because of these known and suspected errors, the calculation of the various injection parameters was made by cross-checking the readings of as many different instruments as were available.

The quantity of solids remaining in the bulk storage bins after the injection was estimated. Bin 1 was essentially full with no evidence that any solids had been removed from it. Bin 2 was essentially full (which was to be expected, since this bin had been recharged during the injection). The solids level in Bin 3 was down 2 to 3 ft. An estimated 40,000 lbs of solids had been removed from Bin 4. The solids consumption during the injection, therefore, must have been about 175,000 to 185,000 lbs (115,000 from Bin 2; 40,000 from Bin 4; 10,000 to 15,000 from Bin 3; and 10,000 to 15,000 from Bin 2 refill).

The accuracy of the waste flowmeter was checked by comparing the flowmeter readings with the tank level readings during those parts of the run that both sets of readings had been recorded; these readings checked within 5%. The flowmeter readings have been assumed to be accurate in the subsequent calculations.

The mix ratio during various injection periods was estimated by three methods. (1) The incremental mass meter totalizer readings were divided by the incremental flowmeter readings to give the mix ratio for that time

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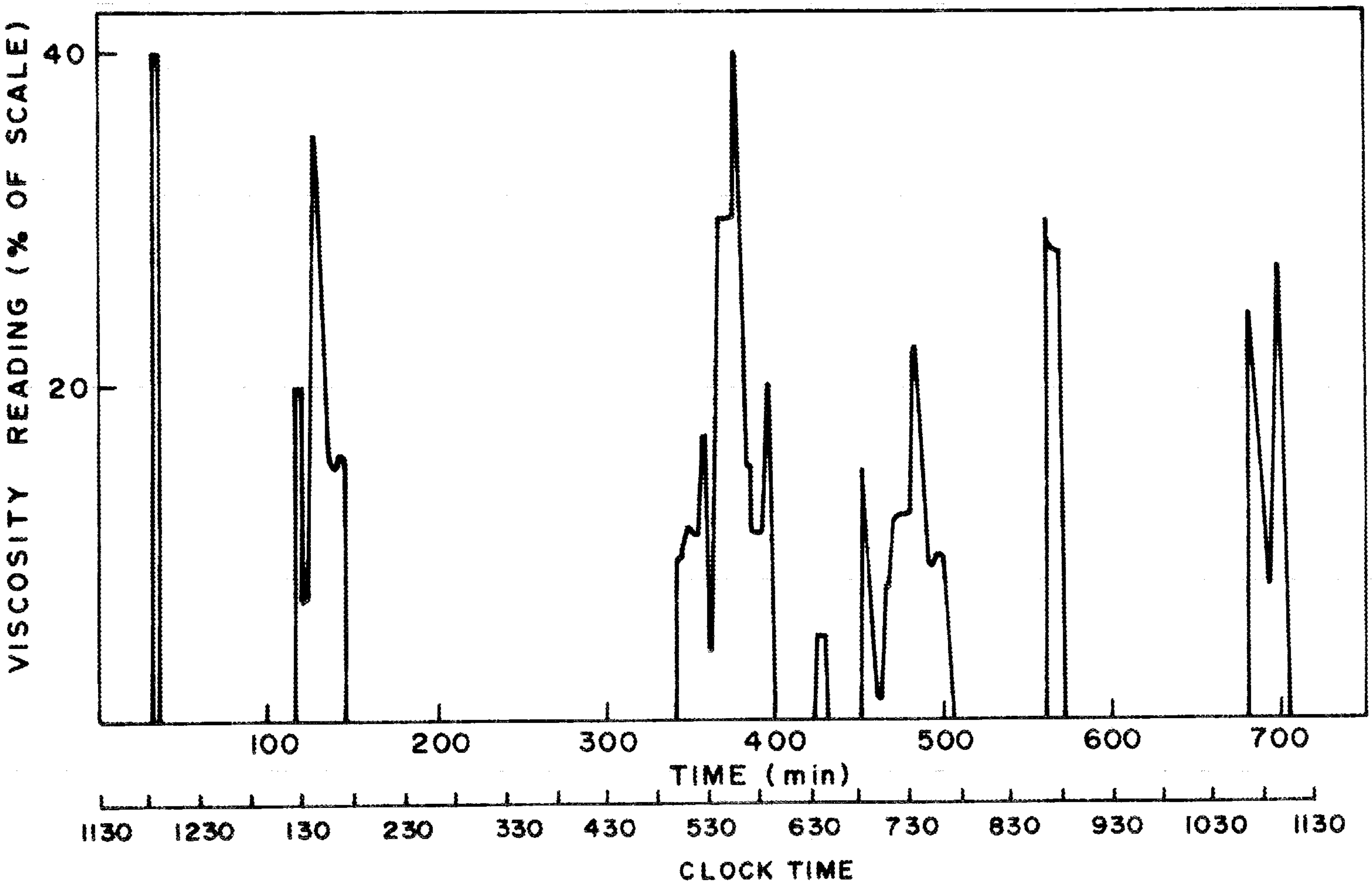

Fig. 6. Viscosity Reading During Injection ILW-12

interval. (2) The incremental slurry flow readings were divided by the incremental flowmeter readings, and the resulting ratio was related to the mix ratio by a correlation obtained from previous injection data. (3) The viscosity meter readings were correlated with laboratory viscosity data to convert these readings to a mix ratio. The results obtained by these methods were then compared. If there was no serious disagreement, the value given by the mass meter was selected. During those periods when the mass meter was obviously inoperative, the mix ratio indicated by the slurry volume increase was selected. The viscosity readings were generally used only for confirmation of the other values.

The volume increase between the waste solution and the grout is a function of the mix ratio and can be calculated from the slurry volume discharged by the injection pump and the waste volume fed to the mixer tub. This volume increase is a rather insensitive indication of the mix ratio, as can be seen in the correlation given in Fig. 7. The data for this correlation was obtained from Injection ILW-9.[1]

The correlation of the viscosity meter readings with the mix ratio was done by choosing several periods during the injection when the operation was relatively smooth and assuming an equivalence between the viscosity readings obtained during these intervals with the mix ratio indicated by the mass meter. The points thus obtained were supplemented with viscosity data obtained from laboratory tests. The correlation that was obtained is shown in Fig. 8.

The mix ratios computed for the four significant operating periods of the injection are shown in Fig. 9. There are a number of obvious discrepancies between the mix ratios computed by the different methods. The mass meter readings were excessive between 4:45 and 5:10, between 6:45 and 7:00, between 7:05 and 7:28, and between 8:15 and 8:55. The measured volume increase was excessive between 7:35 and 8:00 and from 10:50 to 11:15.

A "composite" mix ratio is obtained by judicious selection among the ratios given in Fig. 9. These ratios are then multiplied by the waste volumes pumped during these intervals to give a calculated quantity of solids consumed. This calculated consumption is compared in Table 4 with the consumption estimated from the weight of solids known to be in the bins before and after the injection. The agreement is generally good.

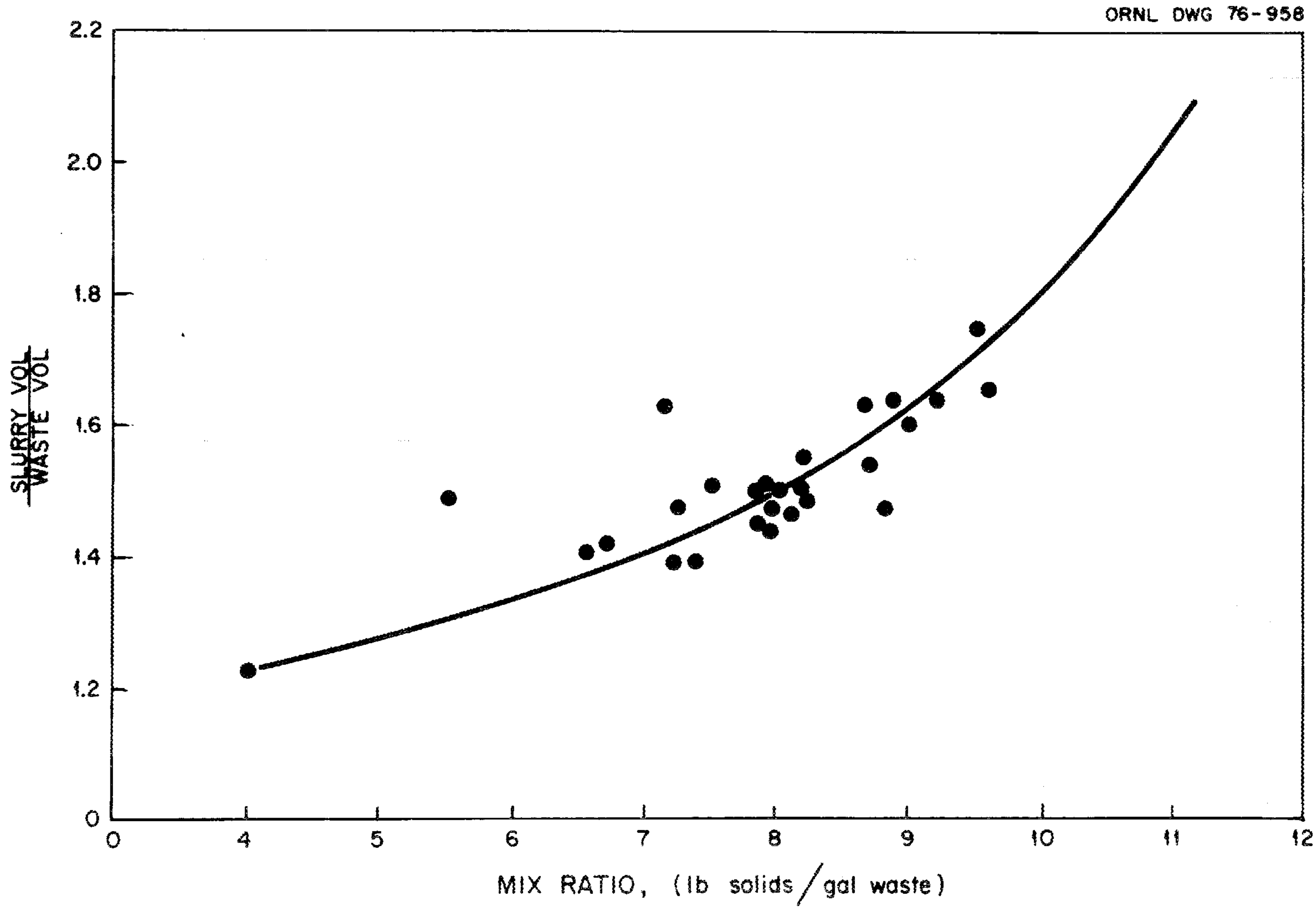

Fig. 7. Volume Ratio Correlation

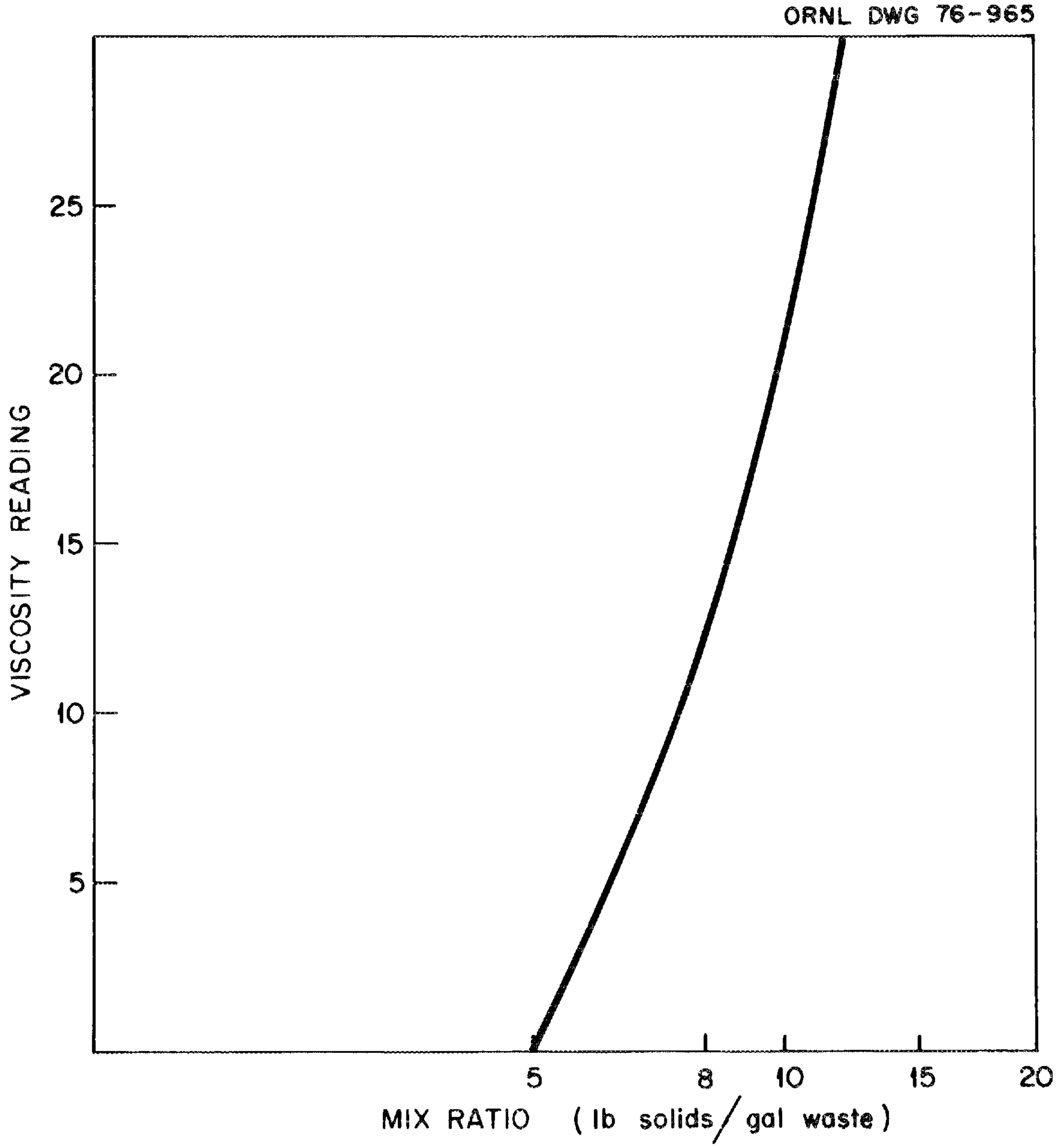

Fig. 8. Viscosity Meter Calibration

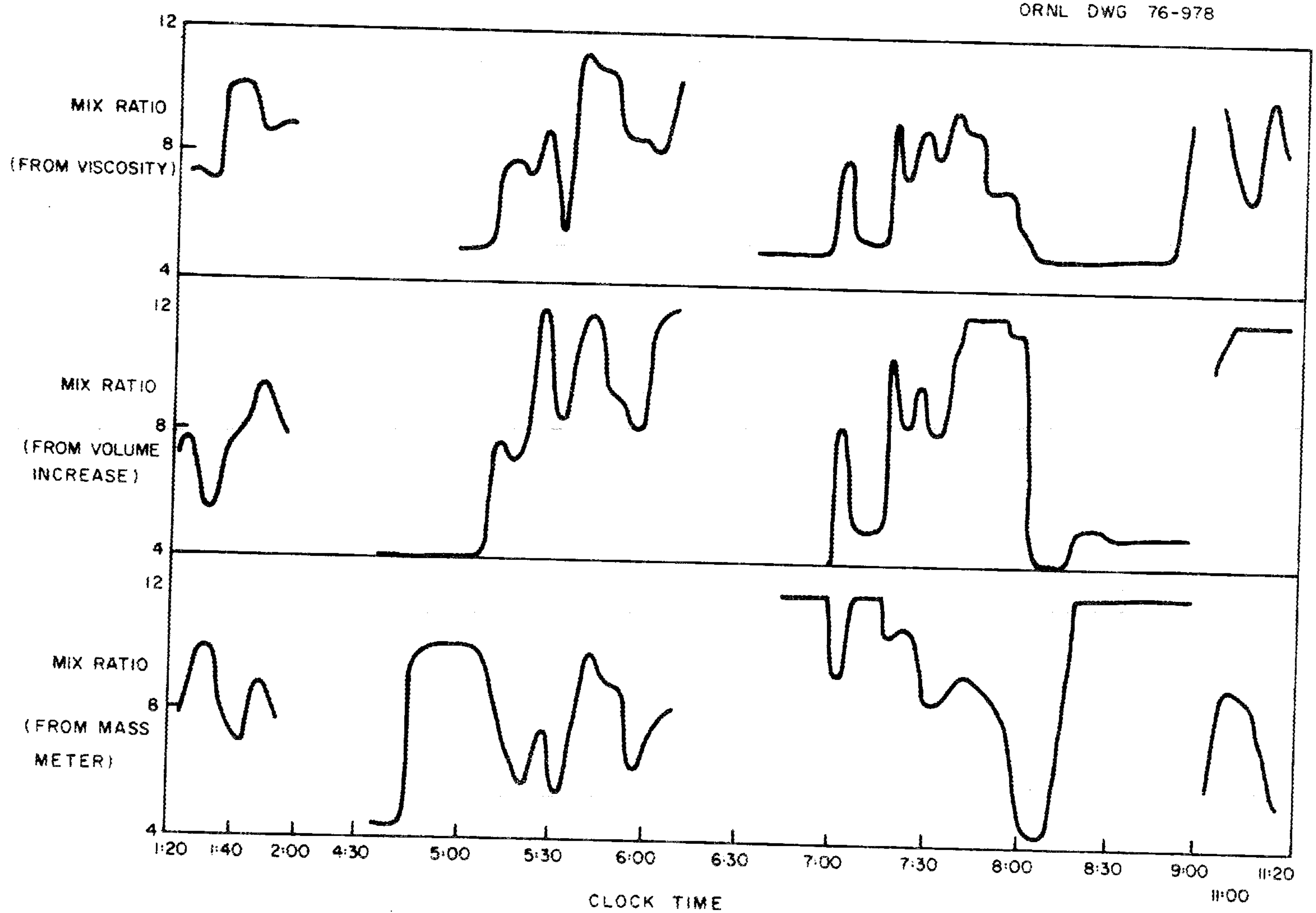

Fig. 9. Mix Ratios for Injection ILW-12

Table 4. Calculated Mix Ratios

Interval From	To	Water Flow (gal)	Waste Flow (gal)	Calculated Solids Consumption (lbs)	Estimated Solids Consumption (lbs)	Mix Ratio lbs/gal
1145	1205	1,726	-	2,000		1.16
1323	1335	600	3,200	30,270		8.0
1625	1810	2,070	7,820	66,430		6.7
1836	1900	-	2,400	11,990		5.0
				110,420 (Bin 2)	115,000 (Bin 2)	
1900 (Bins 3 & 4)	2055	-	10,270	71,490	55,000	7.0
2250 (Bin 2 refill)	2315	-	2,020	14,930	15,000	7.4
Overall		4,396	25,710	197,110	185,000	6.6

The Metritape readings during the emptying of Bin 2 are shown in Fig. 10. There is no discernible pattern to these readings. It might be that the tapes were responding to variations in the pressure of the air in the bins, rather than to the depth of solids. The strain gages could not be evaluated properly. An appreciable quantity of solids was removed from only one bin that was equipped with a strain gage - Bin 4. In this case, about one-third the contents of the bin were consumed and the strain gage indicated 75% full. This is probably only a problem of correctly adjusting the zero of the instrument.

The pressures of the rock cover wells were read just prior to the injection, twice during the injection, and two days after the injection. These readings are given in Table 5. A pressure rise was noted on two wells - NE-125 and S-200.

4.6 Evaluation of Injection

This injection was characterized throughout by the irregular flow of dry solids from the bins (when any flow at all could be obtained) and the presence of large lumps in the solids. These lumps jammed in the mass meter,

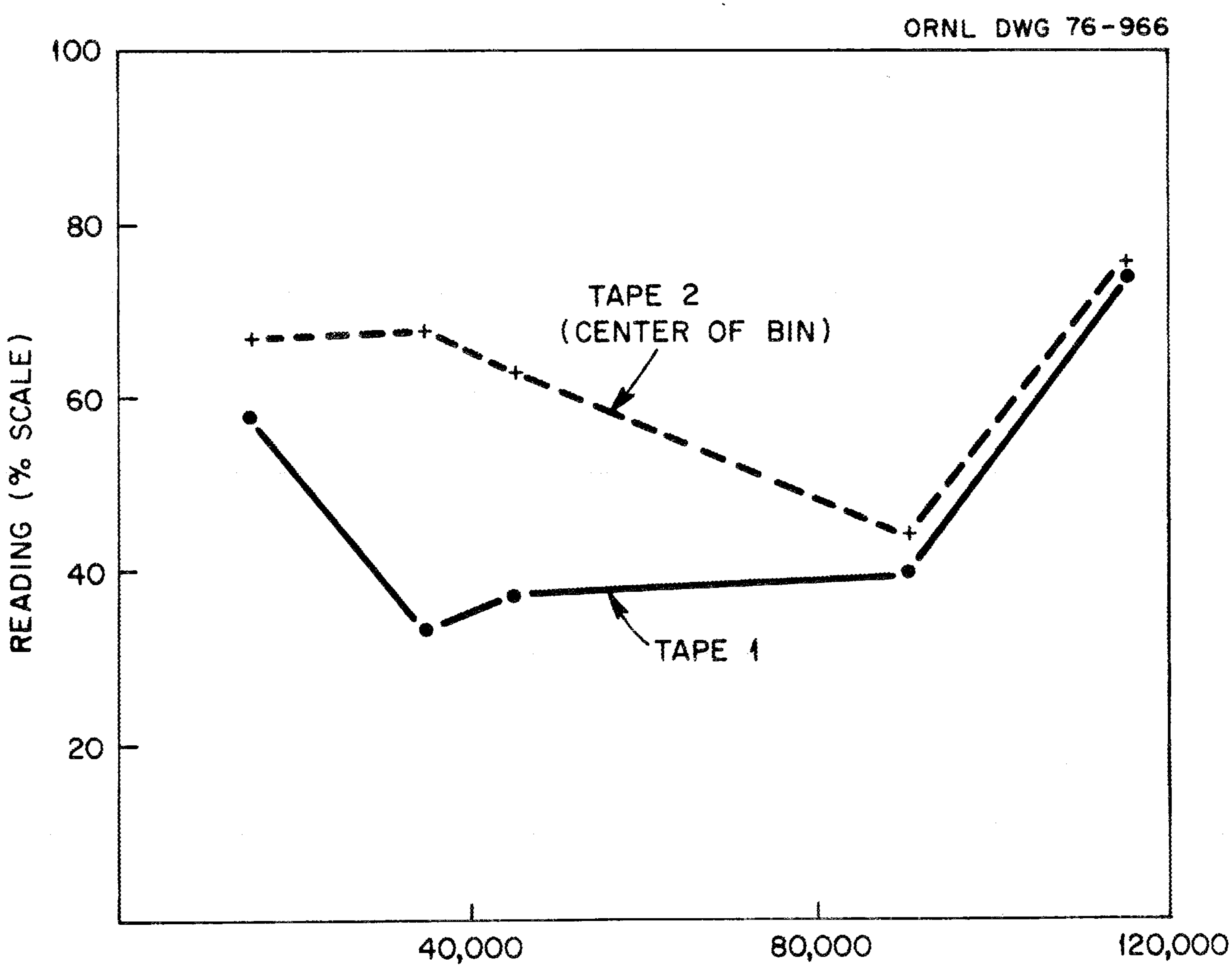

Fig. 10. Metritape Readings for Injection ILW-12

Table 5. Rock Cover Well Pressure Readings

Time	NW-175	NW-250	W-300	S-200	E-300	NE-125	NE-200	N-200	N-275
Pre-injection	-14	2	7	14.5	0	-11	0	0	15
1600	-14	0	7	18	0	0	0	0	15
1830	-14	0	7	30	0	4	0	0	15
Jan. 27	-10	3	5	36	0	5	0	0	13

in the mixer cone, and on the screens to the intakes of the injection pump and greatly complicated the injection. It is most obvious that the solids used in future injections must be fresh and "flowable" if the injection is to be successful.

The best solids flow was obtained from Bin 2, which is the only bin that has been coated inside.

The viscosity meter worked quite well; the Metritapes did not.

5.0 INJECTION ILW-13

5.1 Preliminary Preparations

5.1.1 Waste Transfer and Analysis

A considerable volume (about 40,000 gal) of waste solution remained in the waste storage tanks at the shale fracturing site after the conclusion of Injection ILW-12. This remaining waste solution had all originally come from Gunite tank W-10. In February, additional waste was pumped to the shale fracture waste storage tanks; this new waste solution came from Gunite tanks W-8 and W-10. The distribution of the remaining waste solution and of the two new waste solutions is shown in Table 6.

Composite samples of the waste solutions were obtained during the transfer; calculated analyses of the solutions in the various waste tanks based on this and previous samples are given in Table 7.

5.1.2 Solids Blending

The solids remaining from ILW-12 were emptied from the bins and trucked away.

Table 6. Waste Solution Volumes for Injection ILW-13

Tank	Solution	Volume (gal)
T-1	W-10 (Aug. 1974)	12,750
	W-10 (Feb. 1975)	1,300
T-2	W-8	15,700
T-3	W-10 (Aug. 1974)	23,872
T-4	W-10 (Feb. 1975)	13,900
	W-8	9,700
	Heel	∿600
T-9	W-8	10,600
	Heel	∿2,000

Table 7. Analyses of Waste Solutions

Component	W-10 (74)	W-8 (75)	Mixed (W-8 + W-10 (75)
NaOH, M	0.148	0.472	0.373
$Al(NO_3)_3 \cdot 9H_2O$, M	0.012	0.036	0.028
NH_4NO_3, M	0.06	0.008	0.013
$NaNO_3$, M	1.01	0.158	0.156
Na_2SO_4, M	0.114	0.208	0.184
NaCl, M	0.18	0.042	0.046
Na_2CO_3, M	0.22	0.18	0.16
ρ gm/ml	1.0937	1.066	-
^{137}Cs Ci/gal	0.495	0.305	0.416
^{106}Ru, Ci/gal	-	0.0136	0.0056
^{90}Sr, Ci/gal	0.051	0.022	0.039
^{60}Co, Ci/gal	0.0007	0.0015	0.001

Five batches of dry solids were blended during the week of April 21-25. Four batches were loaded in the storage bins, and the final batch was left in the blending tanks for later transfer to an empty bin. The weights of the various ingredients that were used for the solids mix are given in Table 8.

Table 8. Dry Solids Mix for Injection ILW-13

	Bin 1	Bin 2	Bin 3	Bin 4	P Tanks
Blending date	Apr. 23	Apr. 24	Apr. 22	Apr. 21	Apr. 25
Cement, lbs	47,540	47,930	47,730	47,790	47,780
Fly ash, lbs	42,660	41,800	42,690	38,860	41,040
Attapulgite, lbs	16,800	16,120	17,160	18,900	15,540
Clay, lbs	3,370	2,790	3,690	3,490	3,340
Sugar, lbs	48	48	48	48	48
Total	110,418	108,688	111,318	109,088	107,748

The cement used was Signal Mountain, Type I. The clay used was "Indian Red," supplied by American Art Clay Company. The fly ash came from the TVA steam plant at Kingston, Tennessee. The attapulgite was Attapulgite 150 drilling clay. The sugar was delta glucone-lactone.

5.1.3 Tests of Mix Compatibility

Samples were taken of the blended dry solids from each of the storage bins and one of the blending tanks and tested with water and synthetic waste solutions. Phase separation and rheological properties were determined for grouts made with various mix ratios. Most of the tests were made with grouts that were prepared by mixing the dry solids and waste solution at 5000 rpm (to simulate down-hole conditions), but some tests were made with grouts that had been mixed at 2000 rpm (to simulate tub conditions). Not all combinations of wastes and solids were tested, since a quite large number of tests would have been needed. Instead, each batch of blended solids was tested with only the particular waste solution with which it would likely be mixed during the injection. The tests indicated that the phase separation of the grout in the formation would be less than 2% for a mix ratio of 7 lbs per gallon with W-10 waste and less than 4% for a mix ratio of 7 lbs per gallon with W-8 waste. The mixed waste had no appreciable phase separation at 7 lbs per gallon. The grout "viscosities" were about 20 cp at 7 lbs per gallon and 40 cp at 8 lbs per gallon. Tests with water indicated a phase separation of 9% at 7 lbs per gallon and 4% at 8 lbs per gallon.

5.1.4 Plant Improvement and Maintenance

A dust collector was installed to remove cement dust from the off-gas lines from the mixer hopper and the sump tub. A collection bin was provided to retain the dust collected during an injection.

The diaphragms in the Gadco dampeners were replaced and the units were pressurized.

The leak in the high pressure manifold that occurred at the end of injection ILW-12 was determined to be from one of the high pressure valves in the valve rack. The valve seal had leaked and the flow of grout past the leaking seal had eroded the valve body. The valve was replaced.

The high pressure piping was pressure tested. The injection well was pressurized; the formation fractured at 2400 psi and about 600 gal of water were injected.

5.2 Injection

Sufficient solids were on hand for the injection to permit the injection of all the stored waste solution if a mix ratio that averaged no higher than 6.5 lbs per gallon were used. Tests of the blended solids indicated that only nominal phase separation would be expected to occur if a mix ratio of 7 lbs per gallon were used, and the phase separation would be only slightly higher if a mix ratio of 6 lbs per gallon were used. A mix ratio of about 6.5 lbs per gallon was accordingly chosen for the injection.

The injection was begun at 0915 on April 29. Waste water was pumped from the pit to reopen the fracture; the formation refractured at 2700 psi (injection pump pressure gage); waste flow was started at 0917. The injection ran quite smoothly, in notable contrast to Injection ILW-12. The solids flowed readily, and good control of the mix ratio could be achieved without difficulty. The initial waste flow rate was 138 gal/min; this was increased to about 190 gal/min at about 1040 and held at or near this value for the remainder of the injection.

At 1100 the connector piece between an air slide and the solids feed hopper ruptured. The injection was halted, and the connector piece was replaced; the injection was resumed at 1155.

The injection ran well until 1402; at this time the waste flow was switched from T-3 to T-4. During the valve switching operation, the waste transfer pumps lost their prime and became air bound. The injection was halted temporarily until waste flow could be re-established. During this brief period, the throat of the mixer hopper above the jet mixer became partially plugged with lumps of wetted or partly wetted solids. When the injection was resumed an adequate solids flow could not be maintained, and the solids content of the grout mix was low. After about 20 minutes of difficult operation, the injection was halted briefly and the hopper was washed. The injection was then resumed.

At 1615 the waste flow was switched from T-4 to T-2, and the same difficulty was encountered. The tub and hopper were washed and the injection was resumed. Shortly thereafter, the drain pan of the injection pump was observed to be overfull - the drain line was plugged. The injection was halted again for this line to be cleared. The injection was started again at 1727 and ran well thereafter.

At 1809 flow was switched to the last bin of solids. At this time an estimate of the quantity of solids required to complete the injection indicated that there would be a surplus, so the mix ratio was increased to about 8.0 lbs per gal. At 1905 the last of the waste solution was consumed, and the flow was switched to pit water; at 1915 the flow was switched to fresh water; at 1935 the injection was ended. The well was over-flushed and the equipment was washed.

The pressures of the rock cover wells were read just prior to the injection, four times during the injection, at the end of the injection, and nine days after the injection; these readings are given in Table 9. An appreciable pressure rise was noted in four wells, and possibly significant pressure changes were noted in two other wells.

At 1410 a pressure of 900 psi was noted in one of the observation wells - NE-125. This high a pressure in a cased well is an almost certain indication that the casing was ruptured by the injection.

5.3 Data Analysis

The orifice flowmeter on the waste feed line to the mixer was inoperative for this injection.

Table 9. Rock Cover Well Pressure Readings

	Preinjection	1000	1250	1410	1640	1940	8 May
E-300	0	2	2	2	0	0	3
S-200	25	27	35	36	60+	60+	50
W-300	3	3	3.5	3.5	3.5	2	0
NW-250	1	0	0	0	0	3.5	9
NW-175	-14	-16	-18	-12	-6	16	1
N-275	15	15.5	15	14	11.5	10	10
N-200	0	0	0	0	0	0	0
NE-125	-7	7.5	10	24	21	60+	18
NE-200	13	-7	-6	17.5	6	39	10

The level indicators for the bulk solids storage bins did not give consistently reliable indications. The Metritapes installed on Bin 2 are worthless for this application. The strain gage readings that indicate level changes in Bins 1, 3, and 4 are plotted in Fig. 11 with the corresponding tank inventory weights derived from the mass meter readings. The agreement is quite good for Bin 1 and very poor for Bins 3 and 4.

The bulk storage bins were inspected after the injection. Bin 4 contained an estimated 5600 lbs of solids; the other bins were quite empty. The integrated mass meter readings during the run indicated a close agreement between the instrument readings and the weight of solids known to be in the bins for Bin 2, Bin 1, and Bin 1 refilled. The readings for Bin 3 were also in good agreement after a correction was made to the mass meter readings for a false reading that occurred during a shutdown when solids were plugging the hopper. The mass meter readings for Bin 4 were not in agreement. These readings indicated a total of 127,000 lbs of solids were removed from the bin. Since only 109,000 lbs were charged to the bin and 5600 lbs remained after the injection, some correction to the mass meter readings for this part of the injection is obviously required.

The pump stroke counter readings are plotted in Fig. 12. The waste flowmeter readings are in close agreement with both the waste tank level readings taken during the injection and the pump stroke counter readings. These values are, therefore, used with the corrected mass meter readings to calculate the mix ratio during the injection.

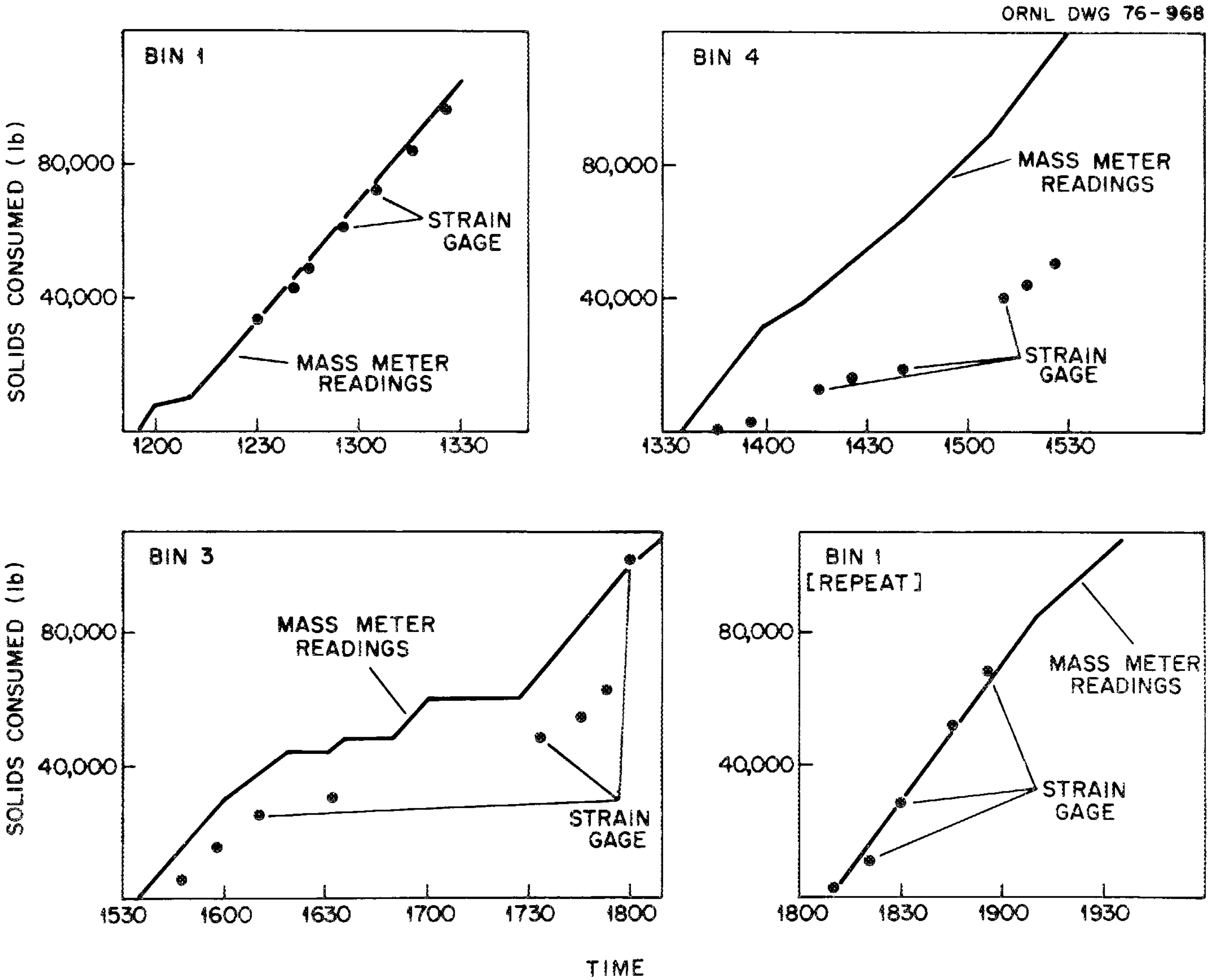

Fig. 11. Strain Gage Readings for Injection ILW-13

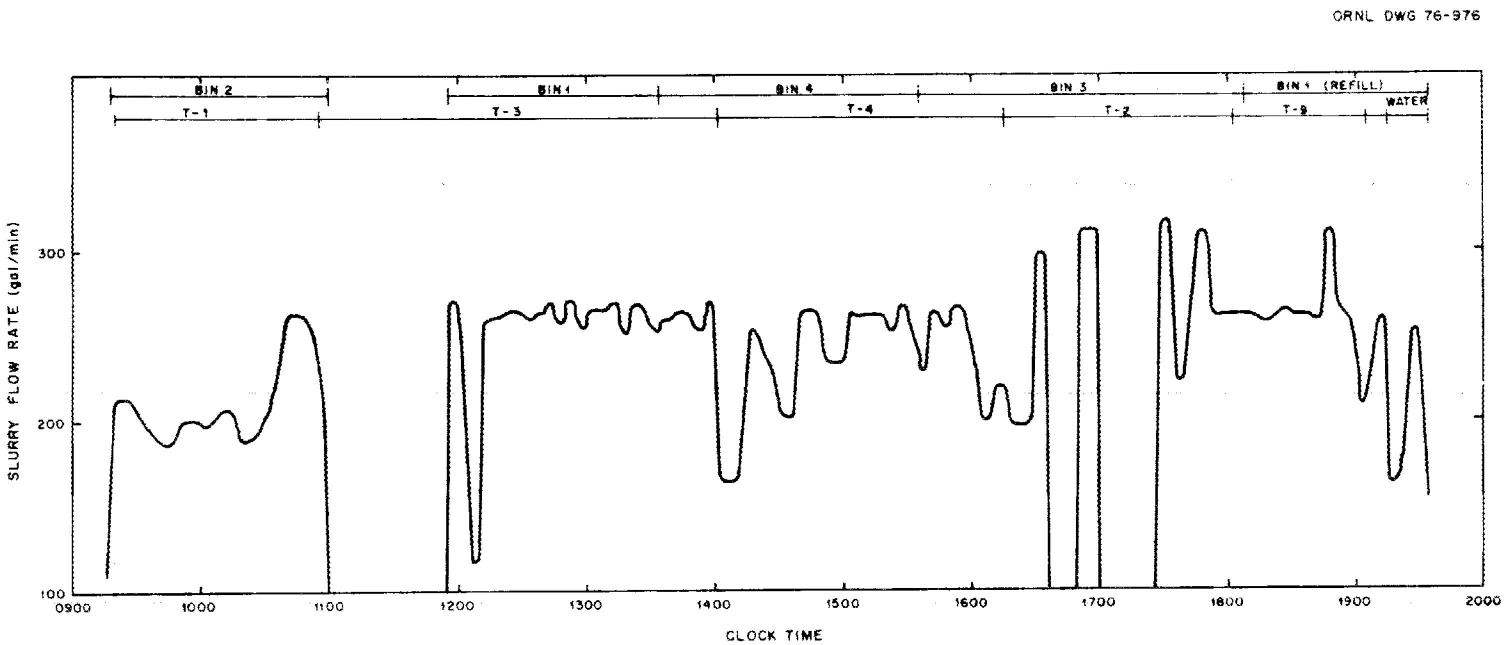

Fig. 12. Flow Rate During Injection ILW-13

The calculated mix ratio during Injection ILW-13 is given in Fig. 13. This ratio is obtained by dividing the solids flow rate over a given time interval by the waste flow rate over the same time interval. A correction was made to the solids flow rate during the interval 1402 to 1535 so that the total quantity of solids withdrawn from Bin 4 would correspond to the quantity actually withdrawn.

In general, the control of the mix ratio was quite smooth during this injection. There were many periods when the injection virtually ran itself, and only minimal control was needed. The two periods of ragged operation and poor mix control were both caused by partial plugging of the solids hopper. The effect of such plugging could probably be minimized by a prompt shutdown of the injection and a cleanout of the hopper.

The viscosity meter did not give reliable results during this injection. The indicated viscosity increased progressively throughout the run - much more than any normal change in the grout properties could account for. It is probable that some sort of grout accumulation was occurring at the sensing probe.

6.0 INJECTION ILW-14

6.1 Preliminary Preparations

6.1.1 Waste Transfer and Analysis

Waste solution was pumped to the waste storage tanks at the shale fracturing site in early and late May. This solution had been stored in Gunite tanks W-8 and W-10. Composite samples of these solutions were taken during the pumping operation; these samples were analyzed to determine the concentrations of various chemical and radiochemical constituents. A nominal composition of these waste solutions is shown in Table 10. These nominal compositions are based on the analytical results, but are slightly adjusted to balance the total anions and total cations. The radiochemical analyses of these solutions are also shown in Table 10.

The distribution of the waste solution among the waste storage tanks at the shale fracturing site is shown in Table 11. The total volume of solution in the waste tanks was 89,000 gal - 25,600 gal of W-8 solution, 54,800 gal of W-10 solution, and 8600 gal of residues.

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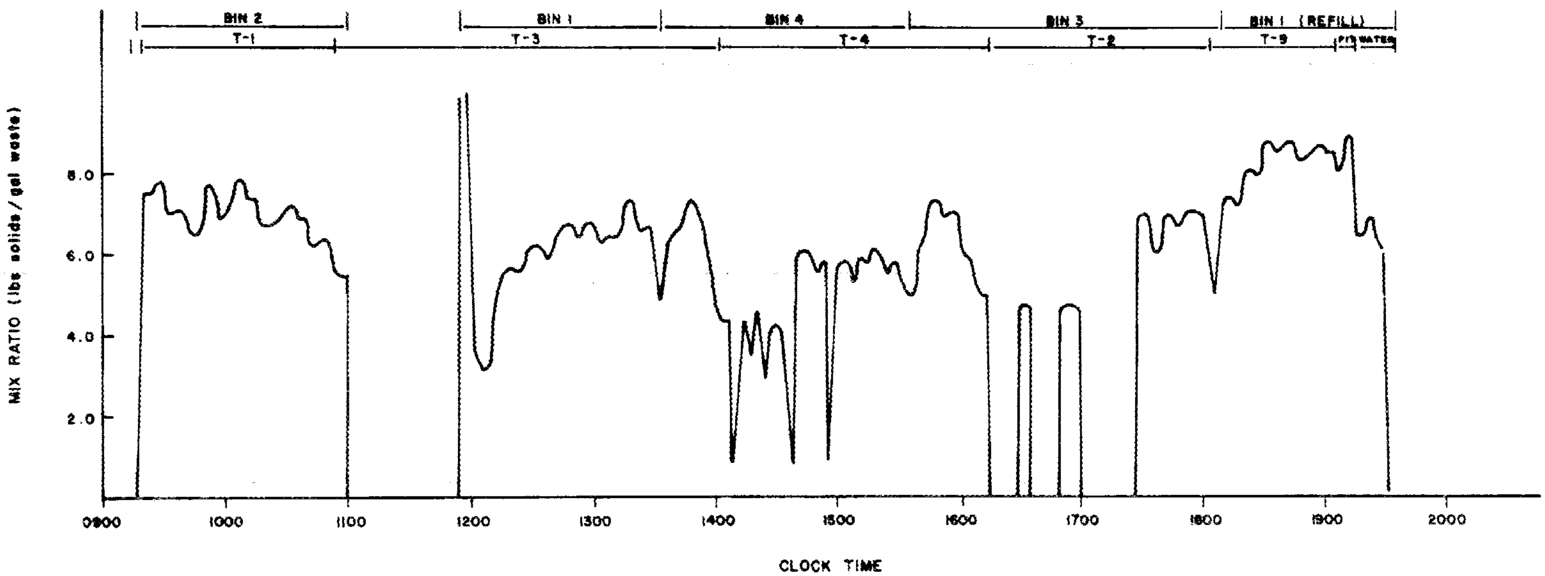

Fig. 13. Mix Ratio for Injection ILW-13

Table 10. Composition of Waste Solutions

Component	W-8	W-10
$NaOH$, M	0.64	0.23
$Al(NO_3)_3$, M	0.034	0.0044
NH_4NO_3 M	0.0028	0.0028
$NaNO_3$ M	0.45	0.24
Na_2SO_4, M	0.089	0.10
$NaCl$, M	0.14	0.13
Na_2CO_3, M	0.16	0.14
ρ gm/ml	1.137	1.1015
^{137}Cs Ci/gal	0.29	0.409
^{90}Sr Ci/gal	0.006	0.047
^{244}Cm Ci/gal	1.8×10^{-4}	6.05×10^{-6}
^{239}Pu Ci/gal	none	none

Table 11. Waste Solution Volumes for Injection ILW-14

Solution	T1	T2	T3	T4	T9
W-8	-	-	21,300	4,300	-
W-10	14,000	13,100	-	15,900	11,800
Residue	800	1,100	2,400	3,600	700
Total	14,800	14,200	23,700	23,800	12,500

6.1.2 Solids Blending

Five batches of dry solids were blended during the week of June 9-13. Four batches were loaded in the storage bins, and the final batch was left in the blending tanks for later transfer to an empty bin. The weights of the various ingredients that were used for the solids mix are given in Table 12.

The cement used was Signal Mountain, Type I. The clay used was "Indian Red," supplied by American Art Clay Company. The fly ash came from the TVA steam plant at Kingston, Tennessee. The attapulgite was Attapulgite 150 drilling clay. The sugar was delta glucone-lactone.

Table 12. Dry Solids Mix for Injection ILW-14

	Bin 1	Bin 2	Bin 3	Bin 4	P Tanks
Blending date	June 11	June 12	June 10	June 9	June 13
Cement, lbs	44,990	46,250	45,440	42,420	46,430
Fly ash, lbs	42,760	43,460	44,190	31,980	36,500
Attapulgite, lbs	26,200	25,650	23,910	22,980	25,960
Clay, lbs	4,020	3,850	3,940	3,880	4,010
Sugar, lbs	48	48	48	48	48
Total	118,018	119,258	117,528	101,308	112,948

6.1.3 Tests of Mix Compatibility

Samples were taken of the blended dry solids from each of the storage bins and tested with water and synthetic waste solutions. Phase separation and rheological properties were determined for grouts made with various mix ratios. Most of the tests were made with grouts that were prepared by mixing the dry solids and waste solution at 5000 rpm (to simulate down hole conditions), but some tests were made with grouts that had been mixed at 2000 rpm (to simulate tub conditions). Not all combinations of wastes and solids were tested, since quite a large number of tests would have been needed. Instead, each batch of blended solids was tested with only the particular waste solution with which it would likely be mixed during the injection. The tests indicated that the phase separation of the grout in the formation would be less than 1% for a mix ratio of 6 lbs per gal with W-8 waste and less than 4% for a mix ratio of 6 lbs per gal with mixed W-8 and W-10 waste. No appreciable phase separation was observed with W-10 waste at a mix ratio of 7 lbs per gallon. The grout "viscosities" were about 20 cp at 7 lbs per gal and 40 cp at 8 lbs per gal. Tests with water indicated a phase separation of 3% at 7 lbs per gallon. Waste W-8 had an unusually high NaOH concentration and was expected to exhibit anomalous behavior in the mix tests, but the grouts prepared from this waste solution differed little from those prepared from the W-10 waste solution.

6.1.4 Preliminary Maintenance

All high pressure valves in the well cell were disassembled and the plug seals and "O" rings were replaced. The diaphragm on one gage protector was found to be ruptured and was replaced. The injection pump was repacked and the Gadco dampeners were recharged. The mass flowmeter and pressure shutdown switch were checked and calibrated.

The injection pump was started and used to recirculate pit water to "break in" the packing. The high pressure piping was pressure tested. The injection well was pressurized; the formation fractured at 2875 psi (annulus pressure) and about 600 gal of water were injected.

6.2 Injection

Sufficient solids were on hand to permit the injection of all the stored waste solution and about 5000 gal of pit water if a mix ratio that averaged no higher than 6 lbs per gallon were used. Tests of the blended solids indicated that no large amount of phase separation would be expected to occur if a mix ratio of 6 lbs per gallon were used. This mix ratio was accordingly chosen for the injection.

6.2.1 Part 1, June 18

The injection was begun at 0838 on June 18. Waste water was pumped from the pit to reopen the fracture. The formation refractured at 3000 psi (injection pump pressure gage). Solids flow was started from Bin 2. At 0855, the flow was switched from pit water to waste solution.

The injection ran quite smoothly; the solids flowed readily and good control of the mix ratio could be achieved without difficulty. At 1031, Bin 2 ran empty and solids flow was switched to Bin 4. The indicated solids flow to this time was 129,000 lbs (119,000 lbs had been loaded in Bin 20, and it was apparent that the mass flowmeter was reading about 10% high.

Shortly after the solids flow had been switched to Bin 4, the flow from the Moyno waste pumps became erratic and could not be maintained at the desired rate. Because the waste flow rate was lower than normal, the pressure at the jet mixer nozzle was too low for efficient operation and the mixer hopper tended to fill with solids. Operation of the mixer became increasingly erratic until at 1100 the injection was shut down. The wiper plug was pumped down the well and the well was shut in. The tub, mixer, mixer hopper, and high pressure lines were washed.

The Moyno pumps were found to be low on oil. Oil was added and the pumps were restarted and run for a short time to establish that an adequate flow rate could now be maintained.

The injection was restarted at 1215. At 1327, Bin 4 ran empty and solids flow was switched to Bin 3. The indicated solids flow from Bin 4 was 105,100 lbs after a correction was made for a false indication between 1101 and 1215 when no solids had been flowing. Since 101,000 lbs had been charged to Bin 4, the mass meter error during this period was apparently less than 5%.

At 1440, the packing on the center plunger of the injection pump failed and grout flowed past the failed packing into the pump cell. The injection was halted. The standby pump was used to pump the wiper plug down the well and to wash the high pressure piping. The tub and mixer and the lines leading to the injection pump were also washed. Grout that had spilled into the pump cell was cleaned up, and the cell and the injection pump were washed.

The following day the injection pump was repacked with new plungers, adapter rings, and packing. Pit water was recirculated for several minutes to "run-in" the packing. The pressure relief valve was tested to 5000 psi, and the disposal formation was refractured at 3500 psi.

The pressures in rock cover wells were read just prior to the injection, three times during the injection, and at the end of the injection. These readings are given in Table 13. An appreciable pressure rise was noted in three wells, NW-175, NE-125, and NE-200.

Table 13. Rock Cover Well Pressure Readings

	Preinjection	0925	1100	1340	1455
E-300	3	4	4	2	0
S-200	41	41	40	41	42
W-300	0	0	3	3	3
NW-250	4	4	3	3-1/2	3-1/2
NW-175	-7	-8	-7	0	1
N-275	11-1/2	11	11	11	11
N-200	0	0	0	0	0
NE-125	5-1/2	19	24	25	35
NE-200	0	5	10	8	14

A plot of wellhead pressure during this phase of the injection is given in Fig. 14.

6.2.2 Part 2, June 20

The injection was restarted at 0845 on June 20. Pit water was mixed with solids and injected for the first 13 minutes of operation to establish that the injection pump would perform adequately. It was quickly found that the transmission of the pump was malfunctioning, and the pump could not be run in the two highest gears. A slurry injection rate of 150 gal/min was about the maximum rate that could be attained. Repairs to the pump transmission would require at least several hours and would have resulted in the postponement of the injection of the remaining waste solution for at least another day and, perhaps, for several days if pump parts were required that were not on hand. The decision to continue the injection at the attainable low rate was made.

The pit water was valved off and the flow of waste solution was started at 0858. The injection ran smoothly at an average injection rate of 142 gal/min. At 0952, the injection was halted for ten minutes to tighten the packing of the injection pump; the injection was resumed at 1002. At 1004, the solids flow was switched to Bin 1. The indicated solids flow from Bin 3 was 136,800 lbs. The total weight of solids that had been charged to this bin was 117,500 lbs; a mass meter error of at least 16% was indicated. An upward adjustment of the indicated mix ratio was made for the next part of the injection to compensate for this error.

Bin 1 ran empty at 1248, and the flow of solids was switched to Bin 2 (which had been refilled with the solids stored in the blending tanks). The slurry injection rate during this time averaged 144 gal/min. The indicated solids flow from Bin 1 was 129,400 lbs; a total of 118,000 lbs had been charged, a mass meter error of at least 10%.

By 1532 no more than a few hundred gallons of waste solution remained in any of the waste storage tanks, and the solution flow was switched to pit water. The solids in Bin 2 were exhausted at 1610, and the injection was ended. The slurry injection rate during this period averaged 144 gal/min. The indicated solids flow from Bin 2 was 166,500 lbs. The charged weight of solids to this bin was 112,950 lbs, so the mass meter error was 47%.

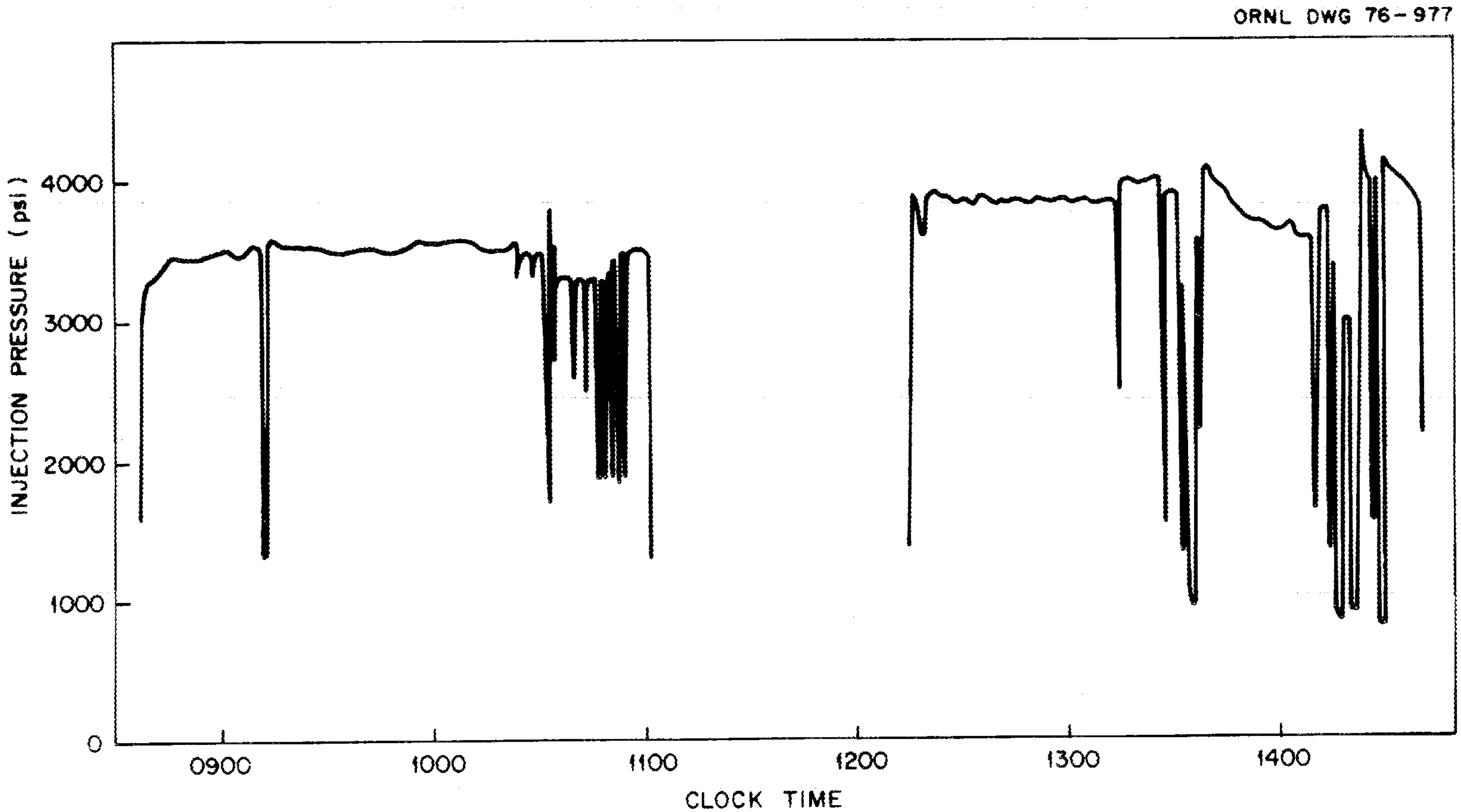

Fig. 14. Wellhead Pressure During ILW-14 (June 18)

As in previous injections, there were several occasions when solids accumulated in the mixer cone and made normal control of the injection virtually impossible. On at least one of these occasions, the level of solids was high enough to lift the sensing cone of the mass meter and give an indication of a much lower solids flow than was actually occurring.

A plot of wellhead pressure during this phase of the injection is given in Fig. 15.

6.3 Data Analysis

The volume of waste solution or pit water that was pumped during this injection was measured by three different methods. The solution flow to the mixer was measured by a Halliburton turbine flow meter and by a recording orifice meter. The volume of waste solution that was pumped was measured by the change in tank solution level. These separate measurements gave somewhat different results, as can be seen in Table 14, but these differences are not large. Some of the smaller volumes given in Table 14 are of doubtful accuracy, since a small error in the choice of beginning and end points could result in a large error in the volume obtained. A comparison of the larger volumes shown in Table 14 shows generally good agreement, and any one of the three sets of values could be used for purposes of calculation without serious error. The turbine meter readings are generally more convenient to use than either of the other values and are, therefore, used in subsequent calculations.

The volume of grout that was injected was measured by the stroke counter on the injection pump. These volumes were recorded at five minute intervals throughout both injection days. A slurry flow rate calculated from these volumes and the corresponding solution flow rate calculated from turbine meter readings are shown in Figs. 16 and 17.

The consumption of dry solids was measured by the Halliburton mass flowmeter. These flowmeter readings were recorded and were also noted at five minute intervals during the injections. The known weight of solids charged to each of the storage bins was used to check the accuracy of the mass flowmeter during the injections. This check was then used to adjust the span of the instrument to bias the subsequent readings by an appropriate amount.

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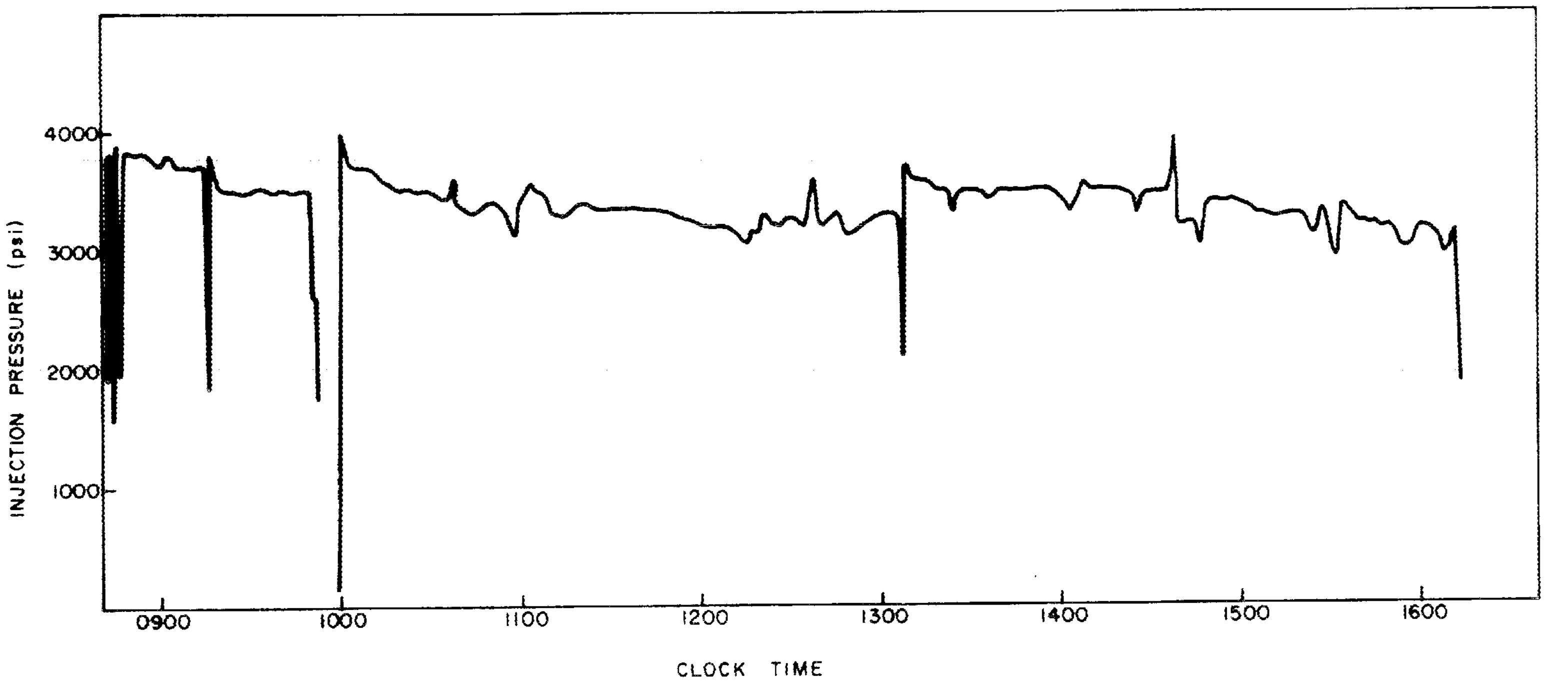

Fig. 15. Wellhead Pressure During ILW-14 (June 20)

Table 14. Comparison of Volume Measurements from Injection ILW-14

Time	Solution From	Pumping Time (min)	Turbine Meter (gal)	Tank Level (gal)	Orifice Meter (gal)
June 18					
0838-0855	Pit	17	3,085		2,961
0855-1055	T-3	120	18,998	19,000	19,662
1055-1100	T-4	5	883	1,300*	828
1216-1219	Pit	3	823	-	501
1219-1415	T-4	116	17,950	17,800	20,775
1415-1440	T-1	25	2,814*	2,500*	3,240
June 20					
0845-0858	Pit	13	1,410	-	1,650
0858-1058	T-1	120	12,075	11,700	12,064
1058-1308	T-2	130	14,033	13,900	14,386
1308-1446	T-9	98	10,922	11,600	10,885
1446-1510	T-3	24	2,555	3,300	2,741
1510-1532	T-4	22	2,447	2,400	2,724
1532-1611	Pit	39	4,243	-	5,072

*The accuracy of these values is low because of end point uncertainties.

The instruments installed on each bin for the measurement of the amount of solids in the bin were totally unreliable except for the strain gage readings on Bin 1. The Metritapes on Bin 2 gave obviously false readings, and the strain gages on Bins 3 and 4 gave quite poor results. The strain gage readings are compared with the mass flowmeter readings in Fig. 18; they look quite similar to the results obtained in Injection ILW-13.

The bulk storage bins were inspected after the injection and were found to be virtually empty - all of the solids charged to the bins were consumed. In the analysis that follows, it is assumed that each bin was essentially empty when the solids flow was switched to another bin. It is standard practice at the end of each injection to attempt to remove any remaining solids from bins that have previously been "emptied" by prolonged aeration and vibration. It is assumed that in this injection no significant amount of solids was left in any of the bins to be removed by this procedure. The effect on the data analysis of an error in this assumption would not be large in any case.

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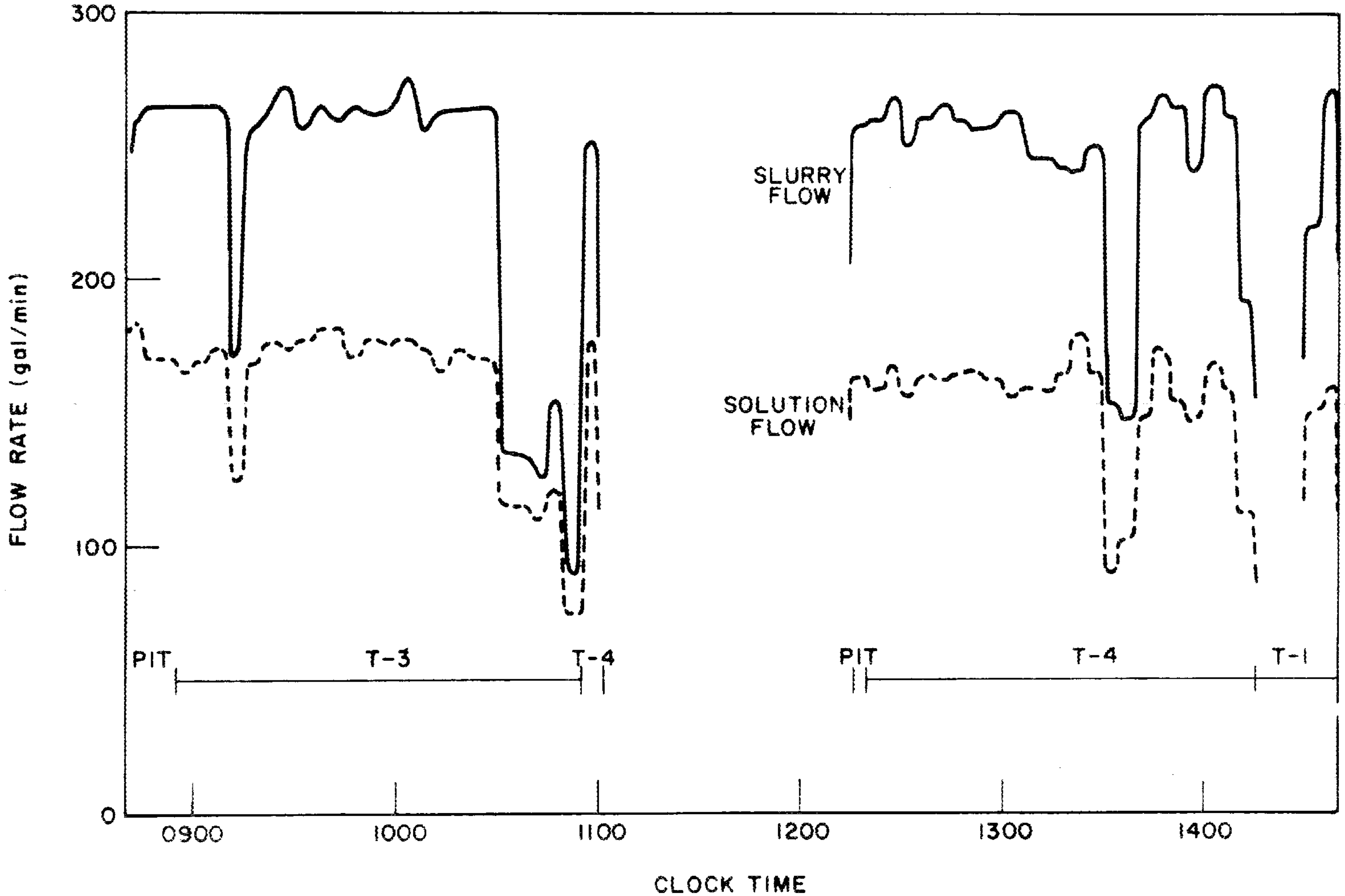

Fig. 16. Flow Rate During Injection ILW-14 (June 18)

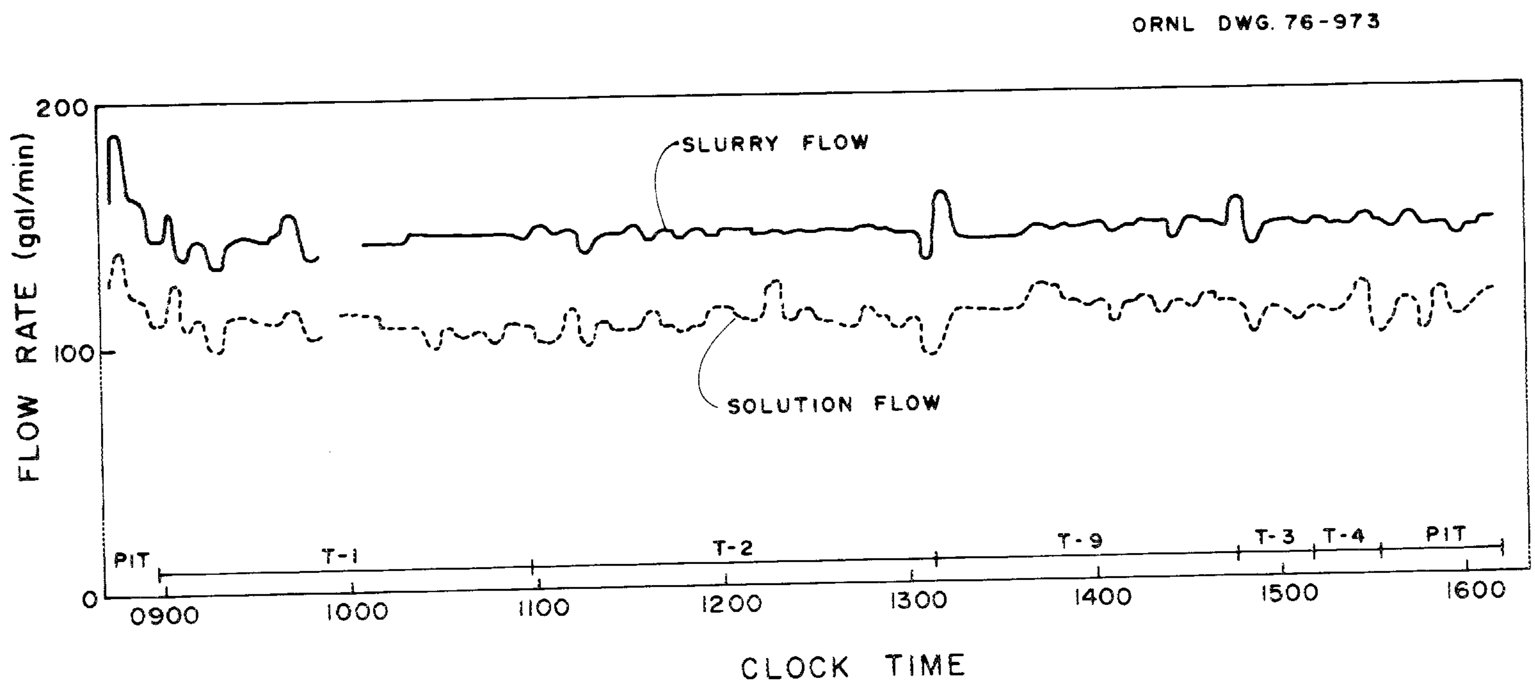

Fig. 17. Flow Rate During Injection ILW-14 (June 20)

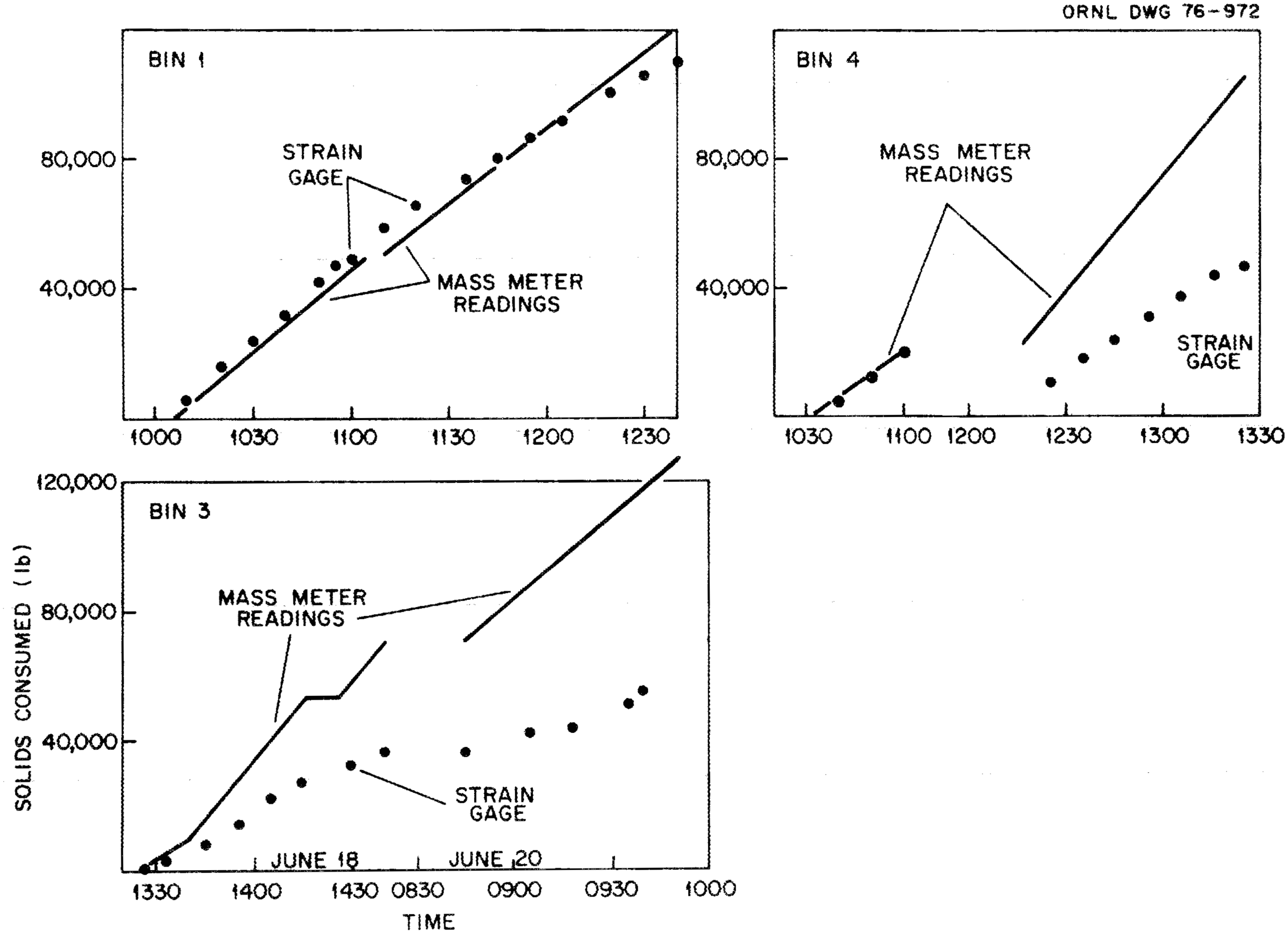

Fig. 18. Strain Gage Readings for Injection ILW-14

The relative viscosity of the grout in the tub was measured with a viscosity meter; these readings were recorded.

The mix ratio (the weight of dry solids mixed with each gallon of waste solution or water) is automatically determined during the injection by a division of the reading of the mass flowmeter (lbs/min) by the reading of the turbine flowmeter (gal/min); this ratio is recorded. The accuracy of this ratio is dependent on the accuracy of the individual readings, which for the mass flowmeter during at least part of the injection is known to be dubious (about 40% more solids were recorded coming out of Bin 2 on June 20 than were charged to it). Some check on the mass flowmeter readings is therefore desirable. Grout viscosity could be one such check, but during this injection the viscosity meter readings did not correlate well with the mix ratio during much of the run; it is believed that this instrument is poorly positioned so that it records the apparent viscosity of the grout in a stagnant zone, which is not necessarily typical of the grout in the whole tub. Another check on the mass flowmeter readings is provided by the ratio of grout volume to solution volume. This ratio is subject to several possible errors; the flowmeter or stroke counter may be misread, the relationship of the volume ratios to the mix ratio is not well known through the whole range of ratios, this relationship may vary considerably between different batches of waste solution and different batches of solids, and any increase or decrease in tub holdup volume between readings would bias the results. Despite these potential errors the volume ratio is a useful check on the mix ratio calculated from mass flowmeter readings.

The solids consumption during various stages of the injection is indicated in Table 15. The values in this table are computed from 1) the weight of solids charged to each bin, 2) the mass flowmeter readings, and 3) the volume ratio. The results in Table 15 indicate that on June 18 the mass meter readings were closer to the bin weights than were the weights calculated from the volume ratios, but that on June 20 the volume ratio gave better results. This is particularly true during the emptying of Bin 2, when the mass meter gave results that were almost 50% high.

The numbers shown in Table 15 are totals for approximate two hour periods of operation. A comparison for shorter periods of operation is given in Fig. 19. In this figure, the mass meter indicated solids consumption

Table 15. Solids Consumption During ILW-14

Bin No.	Wt. Charged	Mass Meter Indication	Calculated from Volume Ratio
June 18			
2	119,260	128,900	151,200
4	101,300	102,200	112,645
3	117,530	77,300	84,450
June 20			
3		59,500	36,595
1	118,020	129,400	102,800
2	112,950	165,900	109,270

calculated from the volume ratio for the same time interval, and this ratio is plotted for the entire injection. In this plot a ratio greater than 1.0 indicates either a high mass meter indication, a low volume ratio indication, or both. A ratio less than 1.0 indicates the opposite situation. A ratio very much different than 1.0 indicates the probability of a major error in one measurement or the other. A near constant ratio that is different from 1.0 suggests an error in the conversion of volume ratio to mix ratio. The curve indicates that on June 18 there was one period in which the two techniques for the determination of solids consumption gave quite different results. At all other times on this day, the ratio was steady at about 0.85. On June 20, however, the ratio was much higher and much more irregular. Since the mass meter totals did not check well with the bin weights on June 20, the most probable reason for the variation shown in Fig. 19 is an irregular error in the mass meter reading. Such an error could be caused by a buildup of solids on the mass meter sensing cone, followed by a sloughing of a part of the buildup. Such buildups have been observed previously, but the necessary correction to the mass meter readings to compensate for them have usually been small. A buildup heavy enough to cause errors of the magnitude seen on June 20 is most unusual.

The calculated mix ratio during Injection ILW-14 is given in Fig. 20. This ratio is based on the mass meter readings for June 18 and on the volume ratios for June 20. The ratio for both days has been normalized so that

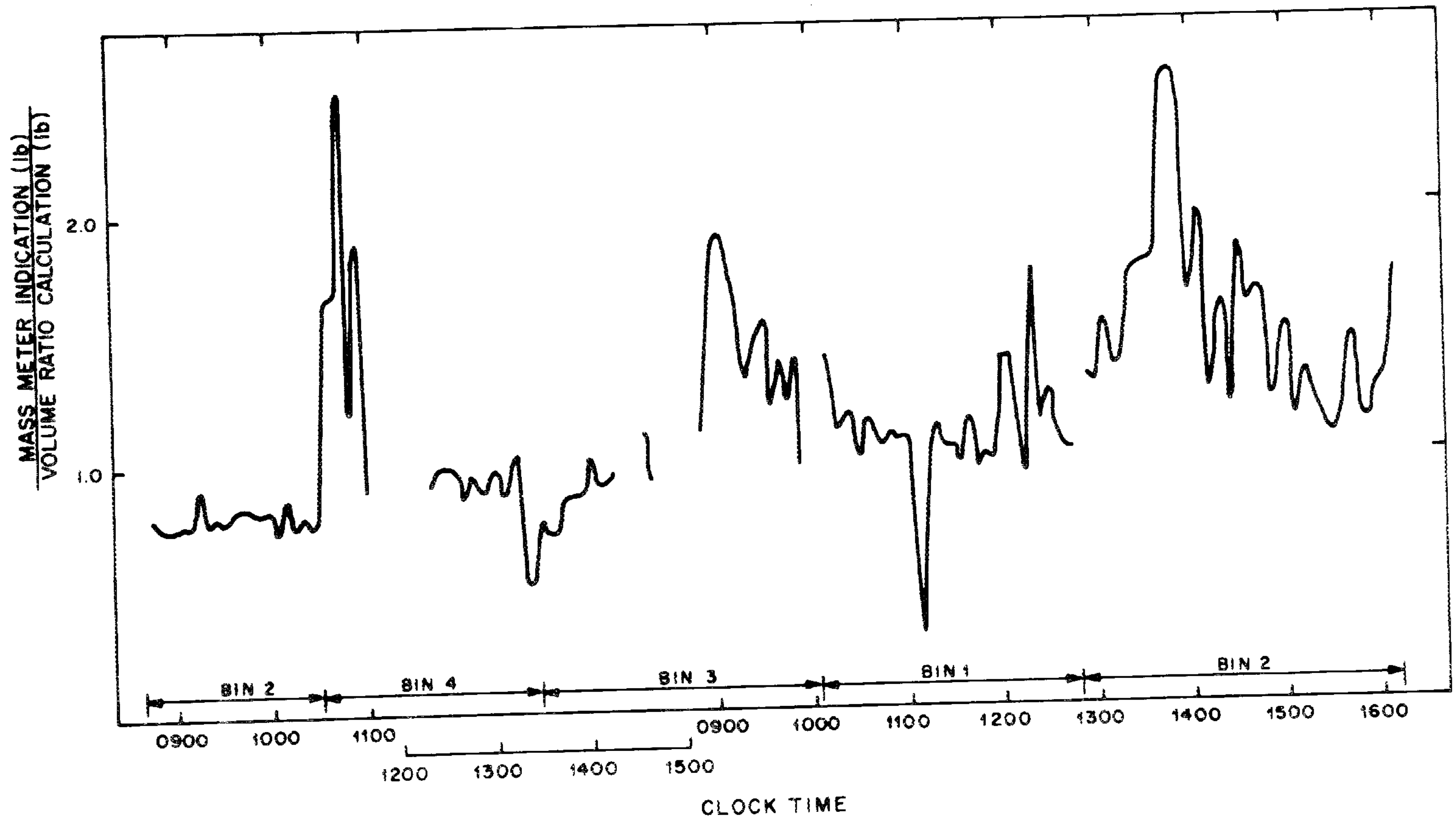

Fig. 19. Ratio of Two Indications of Solids Consumption During Injection ILW-14

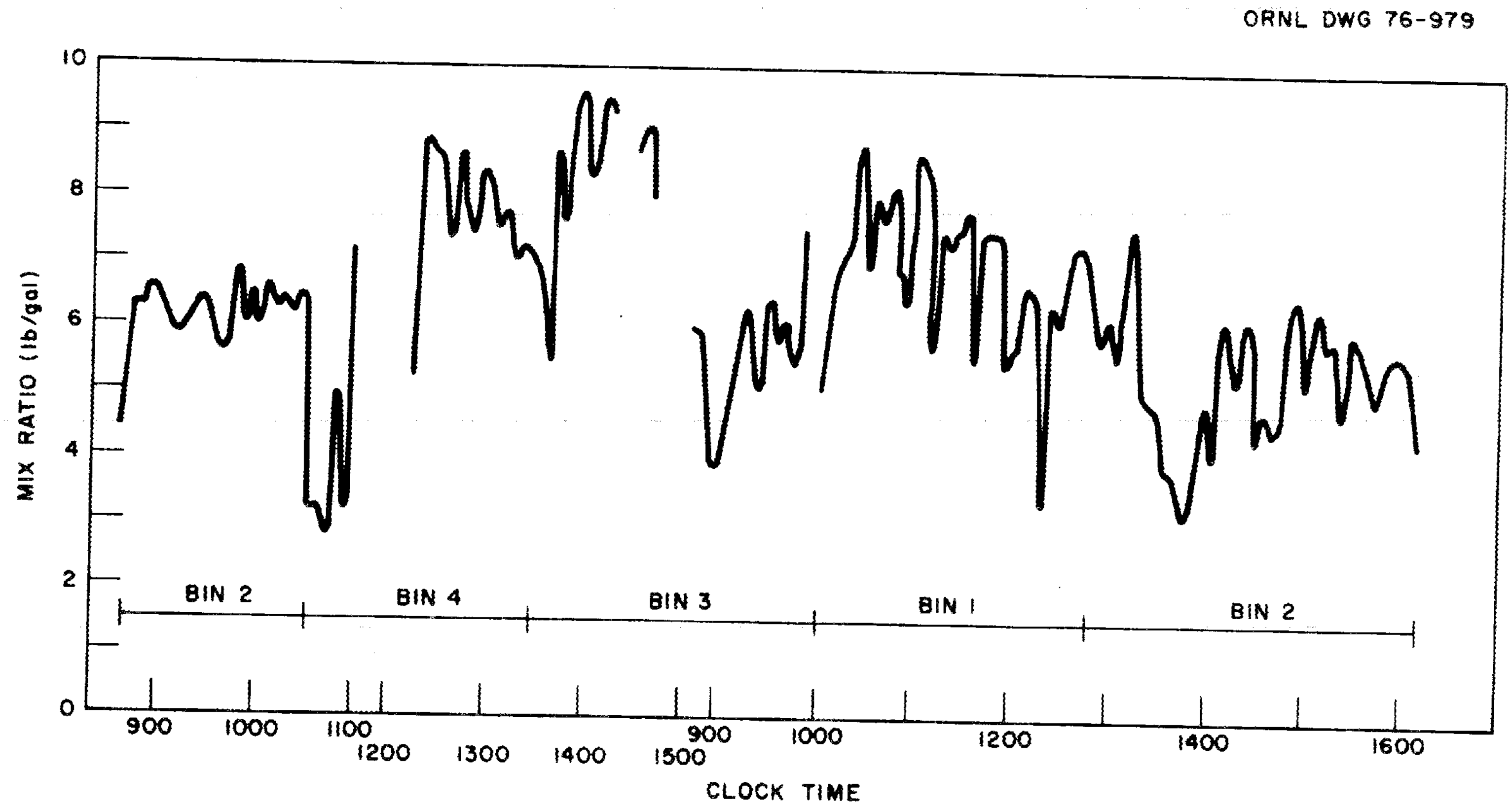

Fig. 20. Mix Ratio for Injection ILW-14

the total quantity of solids consumed would correspond to the quantity originally charged to the storage bins.

6.4 Evaluation of Injection

The most striking incident during this injection was the failure of the packing of the injection pump. This failure forced the shutdown of the injection, resulted in the discharge of grout into the pump cell, and necessitated an immediate cleanup operation before pump repairs could be started. The significance of this incident is not great, however. The injection was halted and the well was shut in according to established procedures. The relatively small volume of grout that had been discharged was cleaned up, the pump was repaired, and the injection was resumed. Failures of this type have been anticipated in general, and procedures have been written to cope. The specific failure that did occur was not anticipated and probably could not have been, and no changes in the procedures are suggested to cope with similar failures in the future.

The control of the mix ratio was considerably more ragged in Injection ILW-14 than in previous injections, particularly during the last half of the injection. The primary cause of the relatively large fluctuations that occurred was the changing bias of the mass meter during this part of the injection. A mass meter bias has been observed in the past (usually caused by solids accumulation on the sensing cone); but, heretofore, it has been relatively constant and a correction for this bias could be made quite easily. In the last half of this injection, however, the solids seem to have built up on the mass meter sensing cone, sloughed off, built up again, and oscillated in this manner throughout this part of the injection. This behavior is shown graphically in Fig. 19. This phenomenon has not been observed in earlier injections. No reason is known why such anomalous behavior should have occurred during this injection, and no cure for the trouble can be suggested. The best approach that can be offered is to check the reliability of the mass meter readings as frequently as possible during the injection and make compensating adjustments when indicated. Up to the present time, the reliability of the mass meter has been checked whenever a bin runs empty - four times during the injection. This check is vital but is obviously not frequent enough to detect more than a relatively constant bias in the instrument; more frequent checks are needed.

Possible ways of making such frequent checks are to use the storage bin strain gage readings (if they can be made more reliable), to use viscosity meter readings (unproven as yet), or to rely on the ratio of the volume of slurry to the volume of liquid as a believable indication of the mix ratio. This volume ratio is subject to several possible errors, but it would be easy to obtain during an injection, could be calculated over as short an interval as desired, and would be a useful check on the mass meter performance. The routine calculation of this ratio during future injections is recommended. During normal operation, the mix ratios calculated from meter readings and from volume ratios should be reasonably close; a wide and continued divergence would be an early indication of instrument error somewhere.

The volume ratio can be calculated from readings taken from existing instruments; an automatic calculation (and recording) of this ratio could probably be obtained with relatively simple modifications to the instrument readouts, however, and would be most worthwhile.

7.0 EVALUATION OF INJECTION SERIES

7.1 Logging Results

The cased observation wells were logged after the completion of Injection ILW-14. A summary of the results of these logs is given in Table 16. All elevations in this table are related to mean sea level.

Table 16. Elevations (in ft) of Grout Sheets in Observation Wells (all elevations are related to mean sea level)

Well	
Injection well	-30
W-300	Plugged; out of service
NW-100	None
N-100	+3
N-150	Small peak at -32; large peak at -28
NE-125	Small peaks at -67 and -65; large peak at -54
E-320	None
S-100	Plugged at +16
S-220	Peaks at -30, -24, -20, and -15; large peak at -11

Two of the observation wells (W-300 and S-100) were plugged during this injection series and are probably unusable in the future. Two of the remaining wells (NW-100 and NE-125) have been ruptured at some time in the past but are still usable. Three wells (N-150, E-320, and S-220) are intact. These three intact wells are the only observation wells at the fracturing site that were constructed to a specification that thus far, at least, have proven to be adequate (a 2-1/2 in. casing with the bottom 300 ft cemented to the well bore with a polymeric water-base gel). The other observation wells had a 1-1/4 ID casing and were cemented with regular cement along the entire tubing length.

The pattern of grout sheets that is indicated by the logging results is similar to the pattern indicated by the previous injection series - grout sheets that are generally flat and horizontal but to the northwest of the injection well are 20 to 30 ft higher than elsewhere. It has long been suspected that a fold exists in the rock of the disposal zone to the northwest of the injection well and that this fold causes locally anomalous behavior of the grout sheet. The logging results of this injection series are consistent with this theory.

The readings of the pressure changes in the rock cover monitoring wells during the three injections suggest a pattern for the grout sheets that is not inconsistent with the logging results. An increase in rock cover well pressure during an injection is assumed to indicate a grout sheet passing beneath the base of the well; on the basis of this assumption, the grout sheet of Injection ILW-12 went northeast and south and perhaps southwest (there are no monitoring wells in the southwest quadrant and no way of verifying this speculation). The grout sheet of ILW-13 went north, northeast, and south. The grout sheet of ILW-14 (June 28) went north and northeast with a finger to the northwest. The complete absence of any pressure change in N-200 is not wholly consistent with this interpretation but can be reconciled with it. In general, these data are suggestive enough to warrant the relatively minor effort required to obtain similar data during future injections. The suggested grout sheet patterns are sketched in Fig. 21.

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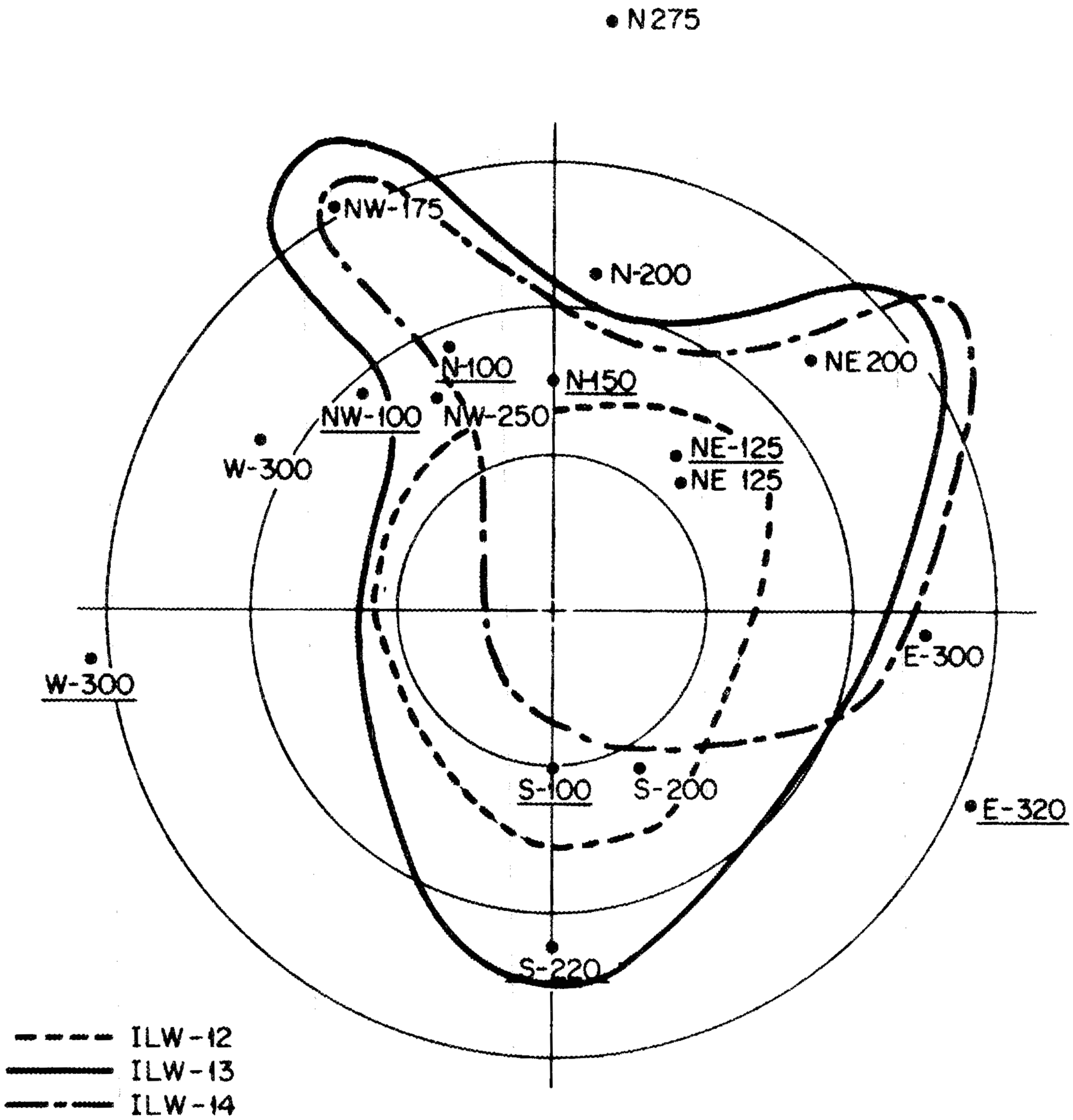

Fig. 21. Grout Sheet Locations Indicated by Pressure Changes in Rock Cover Monitoring Wells

The indicated monitoring well locations are at a depth of 600 ft; the indicated observation well locations are at a depth of 800 ft. The observation wells are underlined.

7.2 Suggestions for Improvement

7.2.1 Mechanical

A good view of the interior of the mix tub is not an absolute necessity for the smooth operation of an injection; as long as the level indicator on the tub is functional and the mix proportioning is reasonably adequate, the injection can be continued even though the view of the tub interior is totally obscured. Operation in this manner is not desirable, however. The apparent fluidity of the freshly mixed grout is a good qualitative indicator of the solids proportion in the mix, and the appearance of a particularly thick or particularly thin grout in the mix tub is frequently the first indication of trouble with the mix proportioning operation. Despite this recognized need, an inadequate view of the mixed grout in the mix tub has been a perennial problem with the Shale Fracturing Facility. It seems to have been aggravated by the 1973 change from a rectangular tub to a round one. Partly because the grout surface is now closer to the top of the tub and more of the splashes that occur will hit and obscure the viewing window; partly because of increased agitation of the tub contents during recent injections; and perhaps partly because of changed flow patterns. Despite the efforts that have been made to remedy the situation, shortly after the last three injections have been started, the viewing window and light ports have been quickly covered with splashed grout on the inside surfaces. The outside surfaces have also been frequently covered with dry solids mix that has leaked from an air slide or connection. The combination of these factors has effectively restricted vision into the mix tub during a significant part of the last three injections. Corrective efforts that have been tried to date have centered on devices for washing the inside surface of the viewing window. These devices have been only partially successful, and something additional is needed to keep this window surface cleaner during an injection. In addition, cleaning devices should be provided for the inside surfaces of the light ports and the outside surfaces of both the viewing window and the light ports.

The 1975 series of injections were marked by occasional interruptions of dry solids flow caused by the dry solids bridging in the mixer cone. Upon some occasions the solids accumulated sufficiently to "flood" the mass meter; this resulted in erroneous mass meter readings, both at the time and usually for a considerable period thereafter. This phenomena usually occurred after a pause in the injection; it was not observed in injections prior to the 1975 series. It is suspected that this condition has resulted from the change in the elevation of the grout discharge into the mixing tub that was made when the new tub was installed after the 1972 injection series. With the grout discharge nozzle at its previous elevation, some wetting of the mixer cone could occur during any pause in an injection, but the extent of this wetting would be relatively small. With the grout discharge nozzle in its present higher elevation, however, the wetting of the mixer cone can be more extensive and can even include the base of the mass meter and the relatively narrow passages between the mass meter and the mixer cone. When the injection is resumed after a pause, the wet surfaces in the mixer cone would temporarily accumulate a crust of damp solids. This crust, if extensive enough, could obstruct the flow of fresh dry solids. The larger the surface area that was wetted during an injection pause, the more likely subsequent trouble with solids flow would be. Any corrective change in the elevation of the grout discharge nozzle at this time would require substantial changes in the mixing system and may not be feasible for some time to come. In the meantime, some method of breaking the solids buildup in the mixer cone is needed, preferably some method that can be operated routinely from outside the cell. A powered scraper bar is one possibility, pulsed compressed air jets is another. Perhaps several devices might be tried, but the need for something has become evident.

Several modifications to the instrumentation of the Shale Fracturing Facility are needed. The viscosity meter should be moved to a position where a stagnant grout layer could not form around the probe and bias the instrument readings. A mounting on an extensible arm so that the probe could be extended into the grout to take readings and retracted at other times is one possibility; a periodic water flush of the probe and its vicinity is another. The strain gages on Bins 3 and 4 should be corrected, and a gage should be installed on Bin 2. The Metritapes on Bin 2 could be removed. Finally, the volume ratio (the volume of slurry pumped divided by the volume of solution pumped) is a significant measure of the injection performance and should be indicated and recorded during an injection.

7.2.2 Procedural

The volume ratio is a useful check on the mass meter performance, and a frequent comparison of this ratio with the mass meter readings should be made throughout an injection. In most injections, such a comparison would have indicated nothing but a general agreement; but in an occasional injection (such as ILW-14) this comparison would have indicated a major mass meter malfunction early enough for corrective action to be taken.

The proportioning of the various dry bulk solids in the solids mix is done by weighing the desired amounts of each solid into a weigh tank. The proportioning is usually close to the desired values, but occasionally it is not. For Injection ILW-14, for instance, the percentage of fly ash in the mix prepared on one day (June 9) was 31.5% (it should have been 38.5%) and the percentage of attapulgite in all mix batches was greater than 20% (it should have been 15.4%). These values are listed in Table 12. This solids proportioning problem arises becauses there are no storage bins for the individual constituents of the solids mix at the injection site. In consequence, the fly ash and cement are brought to the site in bulk transporter trucks (one truck per day of each ingredient). The weight of the cement is usually quite close to the desired weight, but, because of problems at the Kingston Steam Plant loading and weighing stations, the delivered weight of fly ash may be quite different from the desired weight (usually less). When a shortage is discovered, the mix can either be prepared with less fly ash than the recipe calls for or the blending of the last batch of solids mix can be delayed until more fly ash can be obtained. The first choice has been taken to date and no recognized adverse consequences have been observed. Apparently the mix composition can be varied appreciably without large effects on the properties of either the solids mix or the grout. The limits to which this variation can be pushed are unknown, however, and the wisdom of exploring these limits seems dubious. Some extra time spent in proportioning the solids mix could possibly avoid some major troubles.

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