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SHALE FRACTURING INJECTIONS AT OAK RIDGE NATIONAL LABORATORY 1972 SERIES

H. O. Weeren

OAK RIDGE NATIONAL LABORATORY
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CHEMICAL TECHNOLOGY DIVISION

SHALE FRACTURING INJECTIONS AT OAK RIDGE NATIONAL LABORATORY — 1972 SERIES

H. O. Weeren

JUNE 1974

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
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U.S. ATOMIC ENERGY COMMISSION

CONTENTS

Page

SUMMARY 1

1. INTRODUCTION 5

2. DESCRIPTION OF PROCESS AND PLANT 6

3. PREPARATIONS FOR INJECTION SERIES 13
   3.1 Monitoring of Wells 13
   3.2 Level Measurements 14
   3.3 Seismic Measurements 16
   3.4 Strain Measurements 16
   3.5 Facility Maintenance 17
   3.6 Compatibility of Waste and Solids Mix 17

4. INJECTION ILW-8 20
   4.1 Preliminary Preparations 20
      4.1.1 Blending of Solids 20
      4.1.2 Waste Transfer 20
      4.1.3 Compatibility of Waste and Solids Mix 20
      4.1.4 Well Plugging 23
      4.1.5 Well Slotting 23
   4.2 Description of Injection 23
   4.3 Data Analysis 26
   4.4 Radiation Doses Received 32

5. INJECTION ILW-9 32
   5.1 Preliminary Preparations 32
      5.1.1 Facility Maintenance 32
      5.1.2 Blending of Solids 34
      5.1.3 Waste Transfer 34
      5.1.4 Formation Breakdown 34
      5.1.5 Compatibility of Waste and Solids Mix 34
   5.2 Description of Injection 35
   5.3 Data Analysis 36
   5.4 Radiation Doses Received 41

6. INJECTION ILW-10 45
   6.1 Preliminary Preparations 45
      6.1.1 Facility Maintenance 45
      6.1.2 Blending of Solids 45
      6.1.3 Waste Transfer 46
      6.1.4 Formation Breakdown 46
      6.1.5 Compatibility of Waste and Solids Mix 46
   6.2 Description of Injection 51
   6.3 Data Analysis 53
   6.4 Radiation Doses Received 57

7. INJECTION ILW-11 61
   7.1 Preliminary Preparations 61
      7.1.1 Facility Maintenance 61
      7.1.2 Waste Transfer 61
      7.1.3 Blending of Solids 61

Contents (cont'd)

Page

7.1.4 Formation Breakdown..... 63
7.1.5 Compatibility of Waste and Solids Mix..... 63
7.2 Description of Injection..... 64
7.3 Data Analysis..... 67
7.4 Radiation Doses Received..... 71

8. POST-INJECTION EVALUATIONS..... 75
8.1 Seismic Measurements..... 75
8.2 Logging..... 76
8.3 Composite Waste Analysis..... 76
8.4 Bleedback..... 76
8.5 Noise Levels..... 82
8.6 Pressure Measurements for Monitoring Wells..... 84
8.7 Strain-Gage Readings..... 84
8.8 Water Acceptance Rate for Rock Cover Monitoring Wells.... 84
8.9 Uplift Measurements..... 90

9. SUGGESTIONS FOR IMPROVEMENT..... 90
9.1 Compatibility of Waste and Blended Solids..... 90
9.2 Bleedback..... 93
9.3 Waste Injections..... 93

10. REFERENCES..... 95

SUMMARY

A series of four injections of intermediate level waste solution was made during the fall of 1972. A total of 301,520 gal of waste solution containing 100,200 Ci of radionuclides was injected. Prior to this series of injections a large volume of waste solution had been accumulated. The need to dispose of this accumulation of waste and to regain operating flexibility in the tank farm led to the scheduling of the injections as close together as practical (i.e., about three weeks apart).

Several modifications to the shale fracturing facility are scheduled to be installed in 1973. Detailed information on the performance of the existing facility was needed for the design of the proposed modifications, and a particular effort was made to obtain these data from the 1972 injections. 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-8	9-29-72	72,700	8,700	108,600	30,500
ILW-9	10-17-72	68,300	7,300	114,000	24,000
ILW-10	11-8-72	84,760	8,810	132,960	20,800
ILW-11	12-5-72	75,760	6,345	125,490	24,900
	Totals	301,520	31,155	481,050	100,200

Prior to the first injection in the series, two new observation wells were drilled and cemented. Also, a new survey of benchmark elevations was completed. Portions of the high-pressure piping manifold were replaced, and the various instruments were cleared and calibrated. Arrangements were made to obtain seismic measurements during the injection for possible correlation with grout sheet orientation. Also, strain gages were mounted on the wellhead to obtain stress and displacement measurements.

Analyses of the waste solutions to be injected were obtained, and synthetic mixes were prepared for testing with the solids blended for the injection. It was found that the properties of grouts made with plant-mixed solids were significantly different from those of grouts made with laboratory-mixed solids. A set of recommended weight ratios was prepared. When mixed at these weight ratios, solids from the various bins would produce grouts with minimum phase separation.

The existing slot in the injection well was plugged, and the well was reslotted at 832 ft.

The first injection in the series, Injection ILW-8, was made on September 29, 1972. Except for two minor equipment malfunctions, no difficulties were encountered. A total of 72,700 gal of intermediate-level waste (ILW), 5100 gal of contaminated water, and 3600 gal of cleanup water was injected at an overall solids/liquid ratio of 7.3 lb/gal. The activity injected totalled 30,500 Ci. An analysis of the data obtained during this injection indicated the presence of significant errors in the readings obtained for the waste tank levels and the Densometer. Both the injection-pump stroke counter readings and the corrected mass flowmeter readings were used to calculate the weight ratios for various stages of the injection. These values were close to those recommended. Radiation dosages during the injection were low.

Prior to Injection ILW-9, the waste flowmeter and waste tank level indicators that had malfunctioned during Injection ILW-8 were checked and repaired. In addition, other instruments were cleaned and calibrated. Arrangements were made to obtain seismic signals during the injection. The existing fracture was reopened at a pressure of 3600 psi. A synthetic waste solution was tested with the solids blended for the injection, and the results showed that the grouts made from solids stored in different bins had different properties. A set of recommended mix ratios for the solids from various bins was prepared.

The second injection, Injection ILW-9, was made on October 17. Only one minor equipment malfunction was noted. A total of 68,300 gal of ILW waste, 3900 gal of contaminated water, and 3400 gal of cleanup water was injected at an overall solids/liquid ratio of 7.8 lb/gal. The activity injected totalled 24,000 Ci. An analysis of the data obtained during this injection indicated the existence of a continued error in the Densometer readings. The mass flowmeter and waste flowmeter worked satisfactorily; the readings from these instruments were used to calculate the mix ratios for various stages of the injection. These values were close to those that had been recommended. Radiation exposures during the injection were lower than those received during Injection ILW-8 (i.e., they were reduced by about one-half).

Prior to Injection ILW-10, the injection pump was repacked and the plungers were replaced. The mass flowmeter was found to be inoperative and, thus, was removed and cleaned. During the preinjection pressure testing of the high-pressure piping, a fitting on the injection

pump was blown off. After the fitting had been replaced by a plug, testing of the high-pressure manifold was resumed. Examination of the fitting indicated that failure had probably propagated from a crack that had been present for some time but had not been previously detected.

The waste solutions to be injected consisted of a small volume of material remaining from Injection ILW-9 plus a large volume of waste solution with a somewhat different chemical composition. The latter solution was analyzed, and a synthetic solution matching its composition was prepared for testing with the solids that were blended for the injection. It was found that grouts made with this new waste solution were characterized by less phase separation and higher viscosities than those made with previous waste solutions. It was also found (as was the case in earlier injections) that grouts made from solids blended on different days had different properties. A set of recommended mix ratios for the solids from various bins was prepared.

The existing slot in the injection well was reopened at a pressure of 3050 psi.

Injection ILW-10 was made on November 8. Only minor equipment difficulties were encountered; however, it was observed that some solids were retained in the bulk storage tanks and would not feed freely to the mixer. A small fraction (∿6%) of the total solids was held up. A total of 84,760 gal of ILW waste, 7230 gal of contaminated water, and 1580 gal of cleanup water was injected at an overall solids/liquid ratio of 7.1 lb/gal. The activity injected totalled 20,800 Ci.

An analysis of the data indicated the existence of a continued error in the Densometer readings. The mass flowmeter and the waste flowmeter gave satisfactory performance; readings from these instruments were used to calculate the mix ratios for various stages of the injection. Although the values averaged about 1 lb/gal higher than the recommended values, the grout was quite fluid and easily pumped. Radiation exposures during the injection were low, but exposures received during preinjection maintenance were at about the level received during Injection ILW-8.

Prior to Injection ILW-11, the valve seats on the injection pump were replaced and a new Gadco dampener was installed. The existing slot in the injection well was reopened at a pressure of 2550 psi. A synthetic waste solution was tested with the solids blended for the injection, and a set of recommended mix ratios for the solids from various bins was prepared.

Injection ILW-11 was made on December 5. From time to time, difficulties were experienced in initiating and maintaining an adequate flow of solids to the mixer. The solids tended to stick in the storage bins and, during the last part of the injection, bridged in the mixer hopper and restricted the attainable solids flow rate. This resulted in somewhat poorer control of the mix ratio during this injection than was the case in previous injections. A total of approximately 100,000 lb of solids was left in the bins at the end of the injection. Equipment malfunctions included plugging of the waste flowmeter and trouble with the gear shifting mechanism of the injection pump. An analysis of the data obtained in this injection indicated that the Densometer readings were reasonably consistent and in fair agreement with the mass-flowmeter readings for the first time in this series of injections. The mix ratios for the various stages of the injection fluctuated considerably more than usual and averaged about 0.4 lb/gal below the recommended values. A total of 75,760 gal of ILW waste, 5820 gal of contaminated water, and 525 gal of cleanup water was injected at an overall solids/liquid ratio of 7.2 lb/gal. The activity injected totalled 24,900 Ci. Radiation exposures were approximately the same as those received in Injection ILW-10.

No meaningful seismic signals were obtained from any of the injections.

The observation wells were logged after each injection. The vertical movement of the grout sheets in Injections ILW-10 and ILW-11 was greater than had been previously observed, probably because of abnormalities in the shale bedding.

About ten days after each injection, unbound water that existed in the shale beds was bled back through the injection well. The volume of water that was bled back and the rate of bleedback varied considerably and unpredictably between injections. The rate of bleedback decreased drastically as the time of shut-in prior to initiation of bleedback was increased. It is believed that the mechanism involved in bleedback is the squeezing of trapped water from the pores of the grout sheet when the pressure at the injection well is relieved and the overburden compresses the grout sheet.

An analysis of bleed-back solutions indicates that virtually all of the radionuclides are retained by the grout — about 0.02% were recovered in the bleed-back solution.

The strain gage readings that were made on the wellhead indicated that the stresses were small and that fatigue failure is probably not a matter for serious concern.

Changes in pressure of the rock cover monitoring wells during an injection can be correlated moderately well with grout sheet orientation.

Further understanding of the factors affecting waste-mix compatibility is required. Until such understanding is more complete, compatibility tests of each bin of solids and tank of waste should be made. Certainly, a more representative sample would be helpful. A final "hot" test with actual waste solution should be made for final verification of compatibility.

The Densometers are unreliable and should be eliminated. The volume of contaminated water that is injected should be reduced, either by transfer back to the tank farm in Bethel Valley or by reducing the volume that is generated.

In general, this series of injections was made with comparatively few difficulties. The grout was much more fluid than in earlier injections, even though the solids/waste mix ratio was considerably higher than that used previously. As a result of this decrease in grout viscosity, the mixing operation was much easier and the injection pump operated more effectively.

1. 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.

In 1970 the shale fracturing disposal operations were halted, pending a review of the safety and environmental aspects of the process. Operations were resumed in 1972; preliminary preparations for a series of injections were started in July, and the first injection was scheduled for September. Because of the two-year suspension of operations, a large volume of waste solution had been accumulated (∿ 250,000 gal). The need to dispose of this accumulated waste and to regain operating flexibility in the tank farm made it necessary to schedule the injections as close together as practical — about three weeks apart.

Several modifications to the shale fracturing facility were scheduled to be installed in 1973. Detailed information on the performance of the existing facility was needed in order to finalize the design of the proposed modifications; thus, a particular effort was made to obtain these data from the 1972 injections. This report describes the preparations for these injections, discusses the data obtained from each injection, and summarizes the results and conclusions from the series as a whole.

2. DESCRIPTION OF PROCESS AND PLANT

In the shale fracturing process, a given 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

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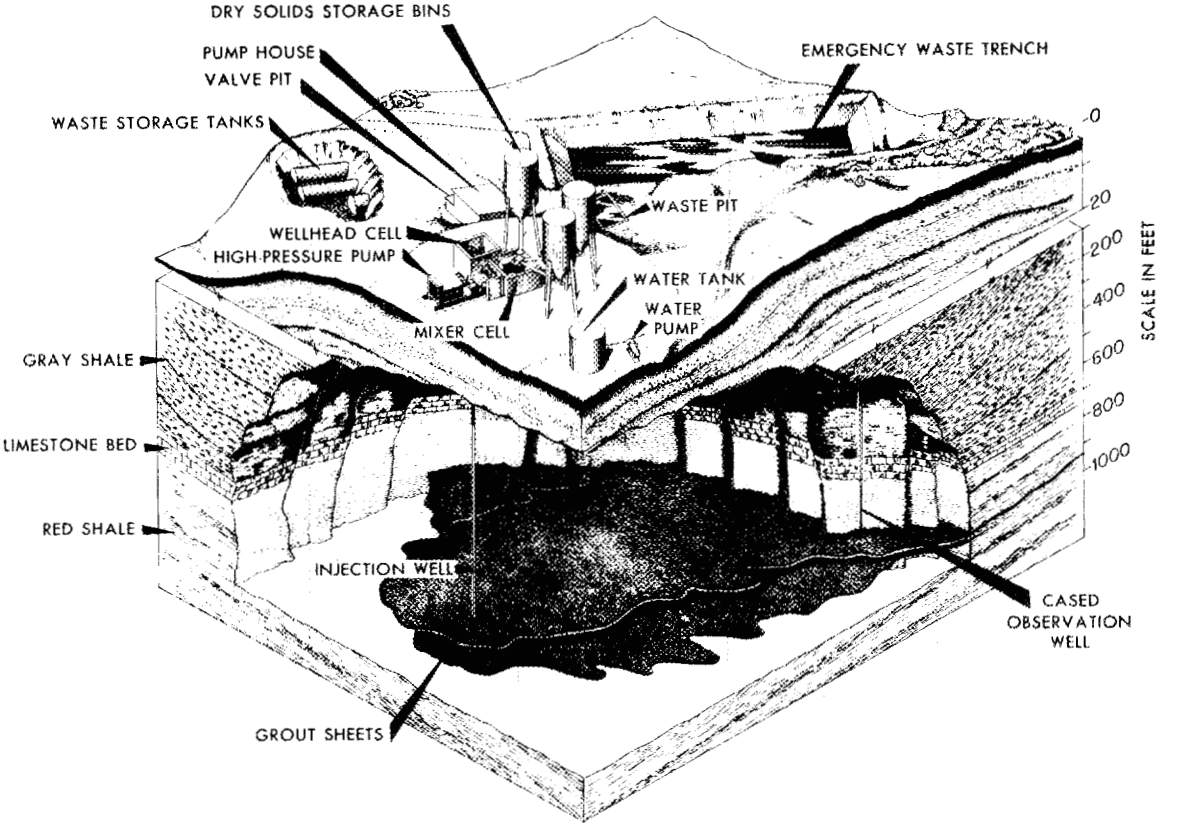

Fig. 1. ORNL Fracturing Facility.

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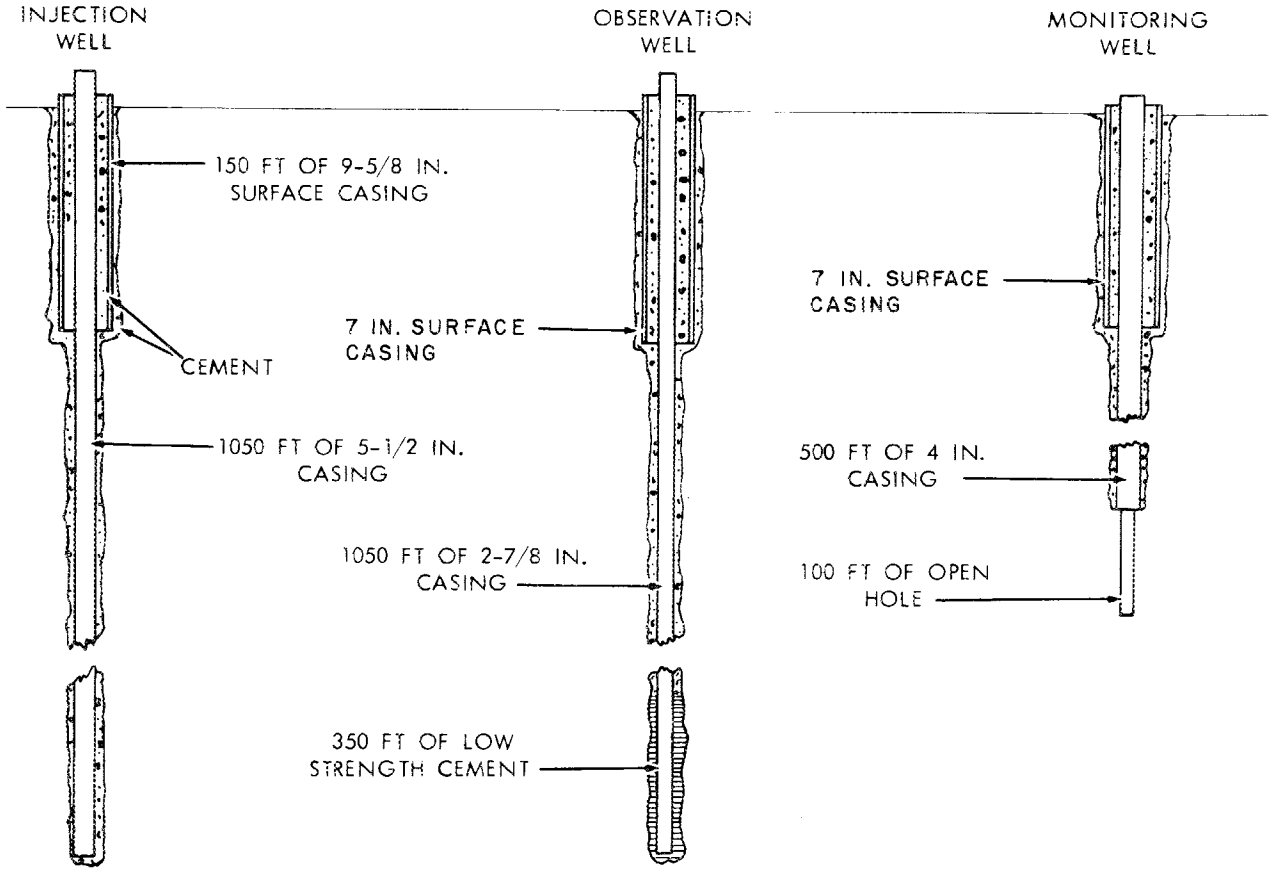

Fig. 2. Sketch of Wells for Fracturing Experiment.

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.

The major process equipment used to inject a batch of waste (see Fig. 3) consists of a waste pump, a mixer, a surge tank, and a high-pressure injection pump. 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, Attapulgus 150, Grundite, 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 subsequently dumped 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.

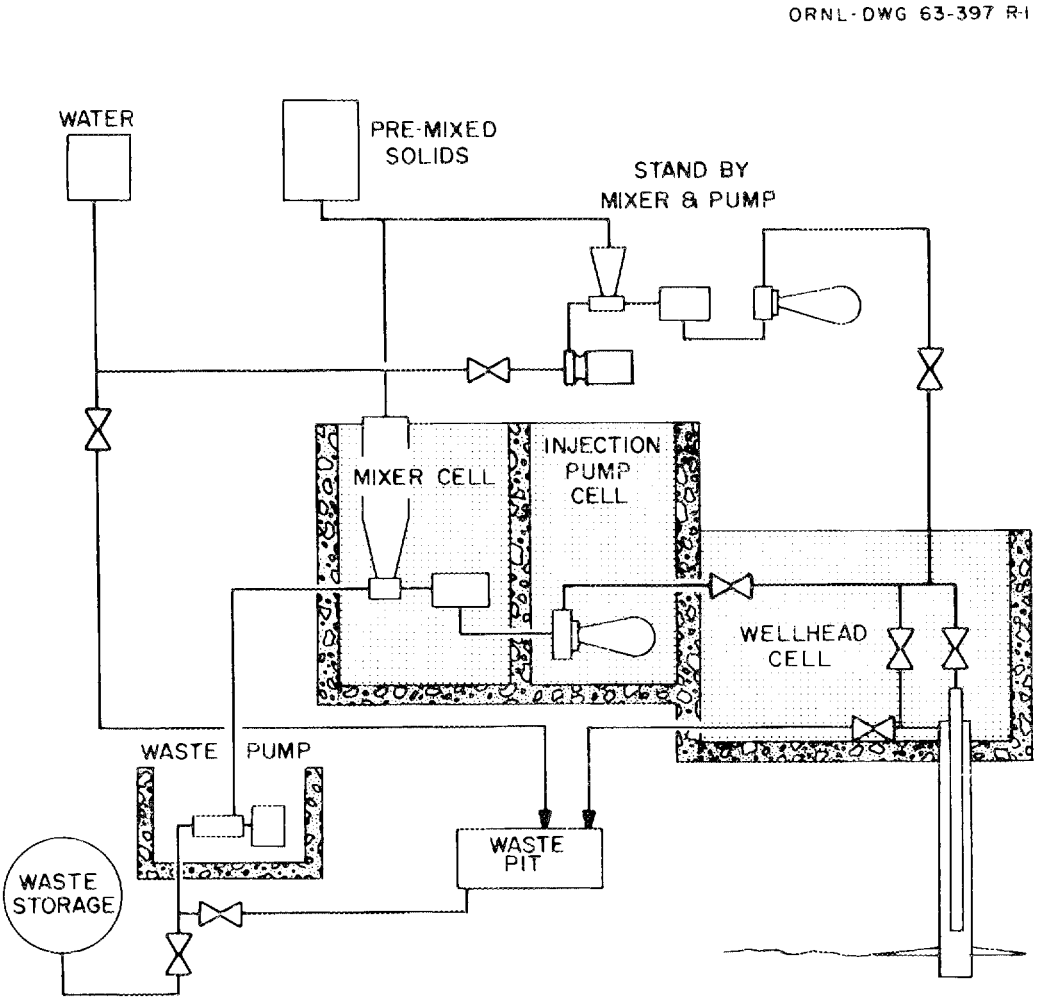

Fig. 3. Schematic Flow Diagram of Shale Fracturing Experiment.

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 arrangements 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. A check on the solids proportioning is 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 pumps grout from the surge tank, through one of two Densometers, and back to the surge tank.

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 will be under considerable pressure (up to 4000 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 7500 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.

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

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

The emergency waste trench is 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 900 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 150 cfm through a demister mounted in the tank and two high-efficiency filters, and then discharges the air out a 40-ft stack.

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, the grout density, 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 several days after each injection. 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 hydraulic fracturing process is described in Reference 1; Reference 2 is the safety analysis of the process.

3. PREPARATIONS FOR INJECTION SERIES

3.1 Monitoring of Wells

Two new cased observation wells, one 220 ft south of the injection well and the other 320 ft east, were installed prior to the first injection in this series. In addition, a largely unsuccessful attempt was made

to clear the plugged observation well at S-100. Also, cores were taken of the shale above the grout sheets in two wells - E-320 and E-300 (rock cover well). These cores were intended for possible use in a future rock mechanics study.

The cased observation wells were churn-drilled by an outside contractor to within about 50 ft of the expected depth of the highest grout sheet. The wells were then drilled the remaining distance by ORNL craft personnel. The tubing (2-1/2 in. J-55) was installed in the well, after which the well was cemented by Halliburton Services* on September 25. A low-strength cement was used for sealing the bottom 150 ft of each well in order to reduce the likelihood that a grout sheet which intersected the well would exert sufficient force on the well to pull the casing apart. A similar low-strength cement, used for the original observation well (N 150), has been found to be more satisfactory than the high-strength cements that were used for subsequent observation wells.

The S-220 well was drilled to 792 ft by the contractor; further drilling to about 840 ft was done by ORNL craft personnel. A grout sheet from a previous injection was intersected at 798 ft (-36 ft in relation to sea level). The resulting contaminated drilling water was contained in an adjacent pit and was periodically trucked away for disposal. About 8000 gal of water, with an alpha radioactivity level averaging 3×10^{-6} μCi/ml and a beta-gamma radioactivity level averaging 3.1×10^{-4} μCi/ml was removed. The total activity removed amounted to 0.9 mCi of alpha-emitting and 9.3 mCi of beta-gamma-emitting material.

The E-300 well was drilled to 820 ft by the contractor; further drilling to 850 ft was done by ORNL craft personnel. No grout sheet was encountered.

3.2 Level Measurements

A new and accurate survey of the existing bench-mark network was made by a crew from the National Ocean Survey.** The results of this survey are shown in Fig. 4. As was the case with earlier uplift measurements, the

*Halliburton Services, Laurel, Mississippi.

**National Ocean Survey, Rockville, Maryland.

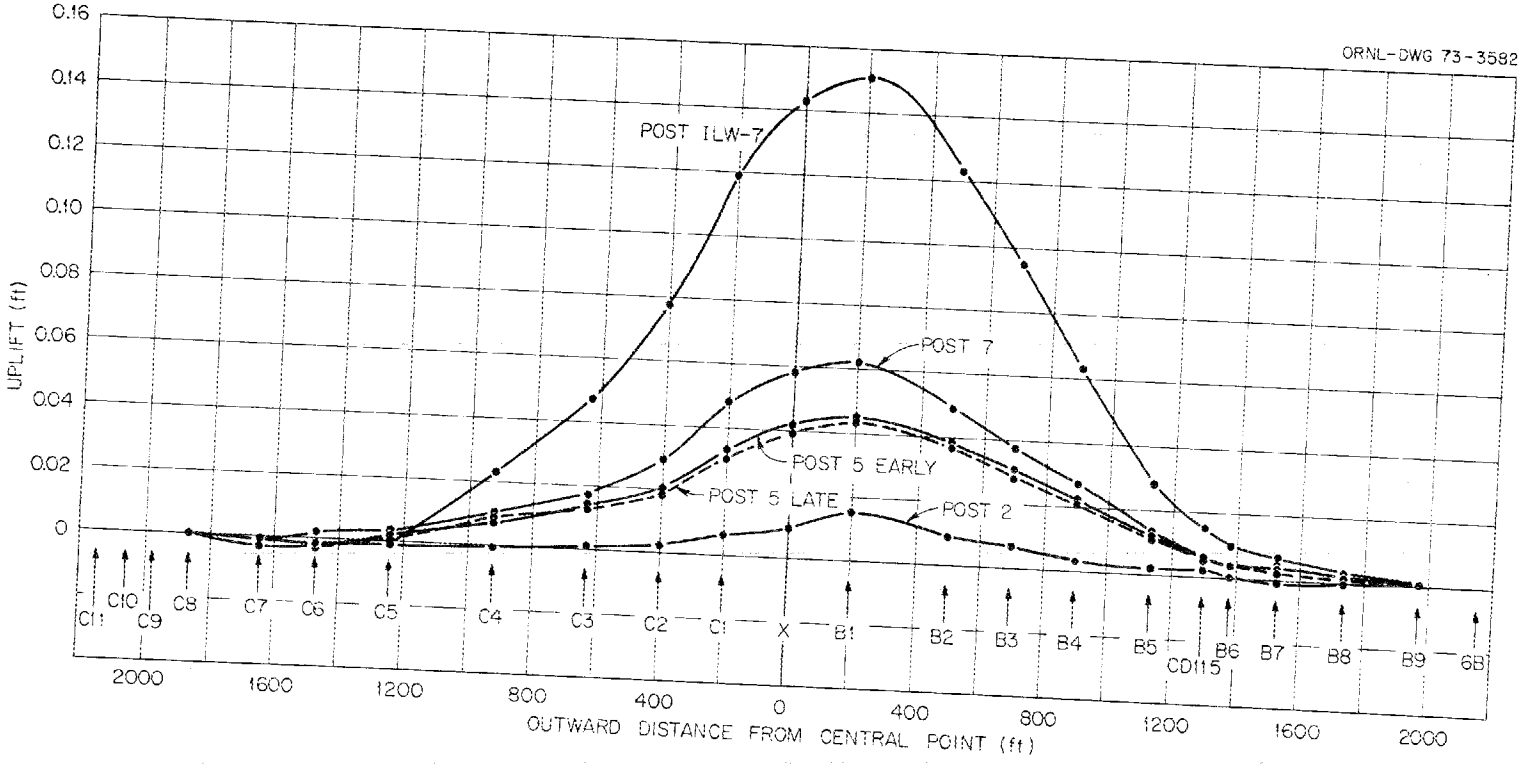

Fig. 4. Surface Uplift at Fracturing Site.

maximum extent of measurable uplift was between 1200 and 1500 ft from the injection well, and the maximum uplift was approximately 0.1 ft per million gal of injected grout.

3.3 Seismic Measurements

The interpretation of seismic signals recorded during Injection ILW-7 in 1970 indicated a grout sheet orientation predominantly to the northeast. This interpretation was not inconsistent with logging results, and this monitoring technique appeared to be a potentially rapid means for determining grout sheet orientation.

A contract was negotiated with Senturion Sciences* to monitor seismic signals during the proposed series of waste injections and to correlate these signals with the grout sheet orientation. An array of six seismometers was used to obtain signals. During the first two injections, the seismometer array was approximately 1500 ft in diameter; during the last two injections, the diameter was increased to 2000 ft. In addition, a downhole seismometer was used during the fourth injection to reduce surface noise and to improve sensitivity.

3.4 Strain Measurements

Some concern was expressed about the magnitude of the stress to which the wellhead fittings are subjected during a typical injection and the susceptibility of these fittings to possible fatigue failure. To determine the magnitude of the stress on the fitting subjected to the greatest displacement during an injection, 12 strain gages and 2 accelerometers were mounted on the plug container, which is immediately above the shutoff valve on the wellhead. Arrangements were made to monitor these instruments during at least two of the four injections and to analyze the results to determine the magnitude of the stresses.

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*Senturion Sciences, Tulsa, Oklahoma.

3.5 Facility Maintenance

Two sump pits were provided for the groundwater drains for the waste storage tanks. No water has ever been observed coming from these drains, and it is not anticipated that any will be released from this source in the future. However, a sump pump was installed in each pit to transfer any water that might accumulate in the sump pits into the emergency waste trench. The volume of the emergency waste trench was determined to be 115,000 gal, which is adequate for current injections.

In other maintenance efforts, plugged Densometer piping was replaced and two new Densometers were installed. The mass flowmeter was reworked and calibrated.

Since most of the piping in the wellhead cell had been installed when the facility was built in 1963, the decision was made that it should be replaced because of its possible vulnerability to fatigue failure. A new master shutoff valve, plug container, and crossover nipple were installed on the wellhead. The sections of high-pressure piping between the injection pump and the valve rack, between the valve rack and the plug container, and between the valve rack and casing shutoff valve were replaced. The injection pump was repacked.

3.6 Compatibility of Waste and Solids Mix

The waste solutions to be disposed of in Injection ILW-8 were stored in two tanks in the ORNL tank farm. Tank W-8 contained about 30,000 gal of waste, and tank W-7 about 100,000 gal. These solutions were sampled and analyzed; the analysis of each is given in Table 1.

The composition of the solids mix to be used in the injections was fixed at approximately that used previously:

Portland cement	2.5 parts
Fly ash	2.5 parts
Attapulgite 150	1.0 part
Grundite	0.5 part
Retarder	0.003 part

Table 1. Composition (in moles/liter) of Waste Solutions in Injection Series

Constituent	Tank			
	W-7	W-8	W-9	W-10
Na^+	1.66	1.24	0.57	0.59
Al^{3+}	0.007	0.037	0.002	0.0011
NH_4^+	0.003	0.03	0.044	0.050
OH^-	0.18	0.28	0.15	0.16
NO_3^-	0.84	1.03	0.30	0.30
Cl^-	0.093	0.217	0.049	0.044
SO_4^{2-}	0.094	0.183	0.111	0.125
CO_3^{2-}	0.193	0.288	0.093	0.10

Because procurement of the necessary quantity of Type II cement (the type used for all previous injections) was not feasible, the substitution of Type I cement was proposed. Results of preliminary mix tests indicated that this substitution would result in only small changes in grout properties; hence, all subsequent work was done with Type I cement.

The initial laboratory tests were made with a synthetic waste solution and a laboratory-blended solids mix. The results of these tests (shown in Fig. 5) indicated that a solids/waste weight ratio of 6 to 7 lb/gal would have acceptably low phase separation. Measurement of the viscosity of the grout made with W-7 waste gave 2.2, 5.0, and 20 P for weight ratios of 5.0, 6.0, and 7.0 lb/gal, respectively. Therefore, since a grout viscosity of less than 10 P is desirable, a weight ratio of 6.0 lb/gal was indicated for the injection.

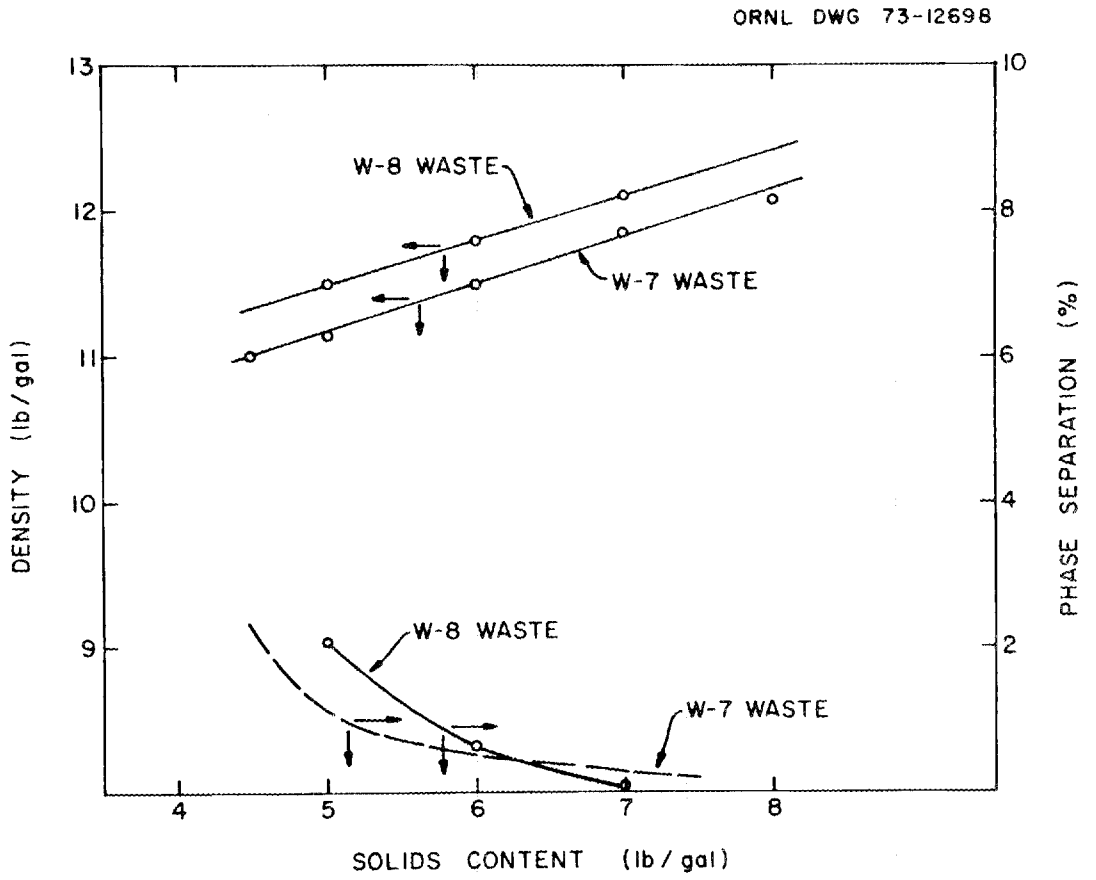

Fig. 5. Density and Phase Separation of Grout Prepared from Waste Solutions W-7 and W-8 (Laboratory-Blended Solids).

4. INJECTION ILW-8

4.1 Preliminary Preparations

4.1.1 Blending of Solids

A total of 595,721 lb of solids was blended and stored as follows:

Container	Weight, lb	Date
1	134,098	9-18-72
2	119,814	9-21-72
3	115,124	9-20-72
4	145,046	9-19-72
P-1 tank	40,461	9-22-72
Scale tank	41,178	9-22-72

4.1.2 Waste Transfer

Waste solution was pumped to the site from tanks W-7 and W-8 and distributed as follows:

W-7 Waste, gal	W-8 Waste, gal
T2 - 14,448	T1 - 14,327
T3 - 24,385	T9 - 12,850
T4 - 24,334	

4.1.3 Compatibility of Waste and Solids Mix

After the solids required for the injection had been blended and stored, the solids at the top of each bin were sampled. These samples were mixed with synthetic waste solutions and water according to the procedure used in the initial tests. The results obtained with W-7 waste solution are shown in Figs. 6 and 7; the results with water and W-8 waste solution were similar. It is obvious that there is considerable variation in the phase separation observed with grouts made from solid mixes stored in different bins. A comparison with Fig. 5 indicates that there is also a considerable difference between the phase separation observed with grouts made from laboratory blends and that observed with grouts made from plant blends. A partial check on the completeness of the solids mixing was made

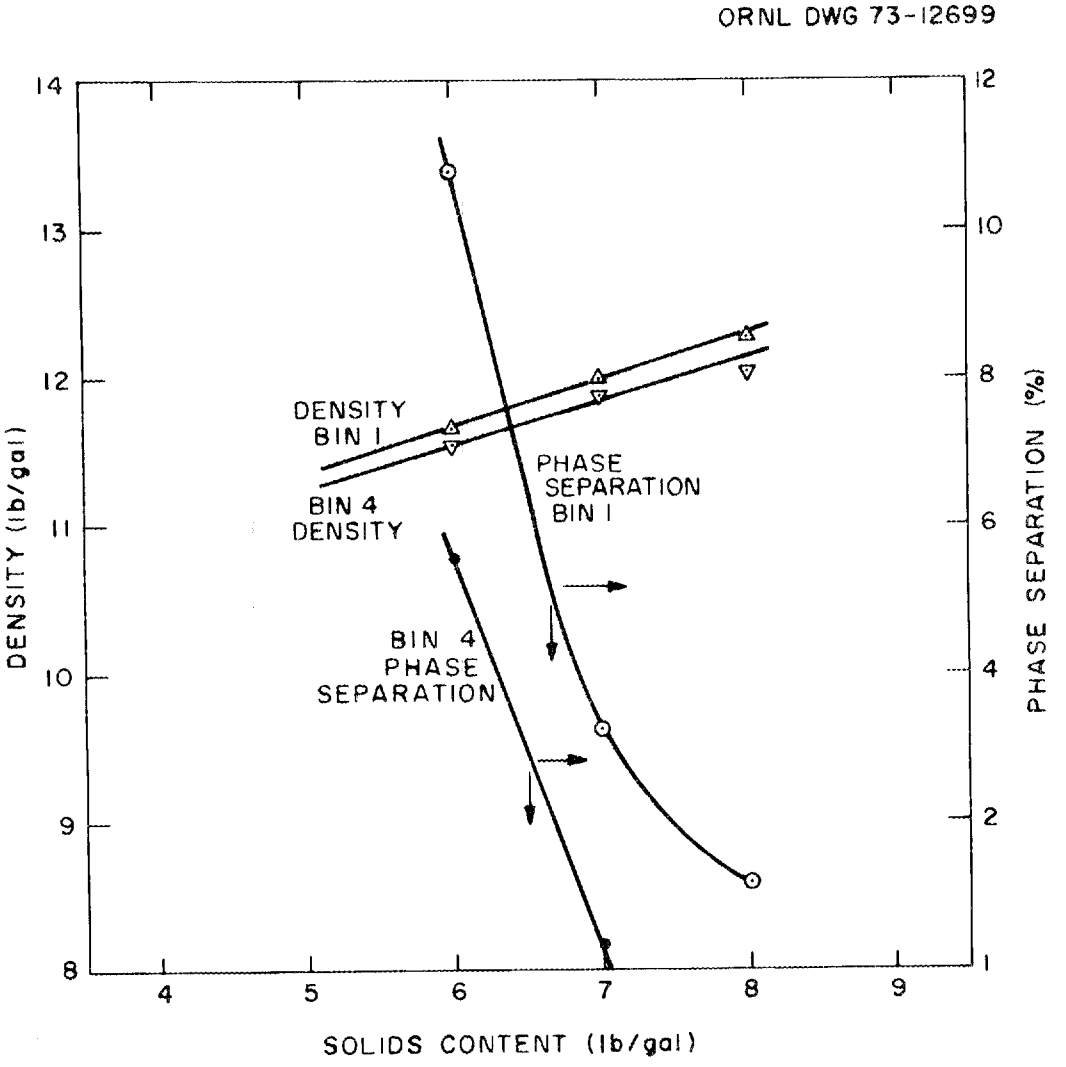

Fig. 6. Density and Phase Separation of Grout Prepared from Waste Solution W-7 and Solids Stored in Bins (Plant-Blended Solids).

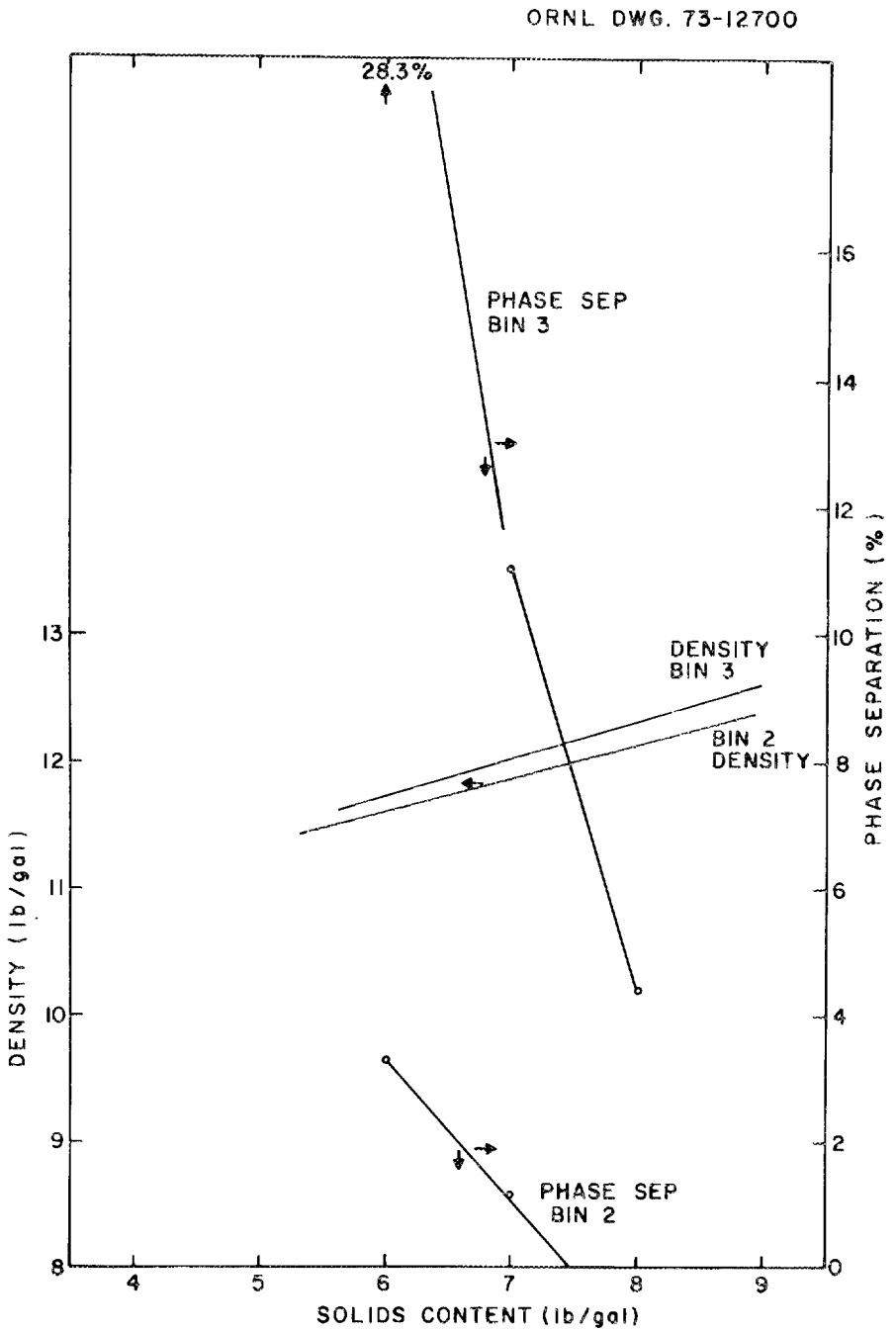

Fig. 7. Density and Phase Separation of Grout Prepared from Waste Solution W-7 and Solids Stored in Bins 2 and 3 (Plant-Blended Solids).

by sampling the solids at the bottom of bulk storage bin 1 and comparing the grouts made from this sample with those prepared from a sample taken from the top of the same bin. The grouts had similar properties; for example, at a weight ratio of 6 lb/gal, the grouts made from the top and the bottom samples had 11% and 16% phase separation, respectively. Therefore, it was tentatively concluded that the solids had been adequately mixed and that the observed differences in grout properties were due to variations in cement composition. It was decided that the solids/waste weight ratio should be varied during the injection, depending on which bulk storage bin was feeding solids to the plant, and that the weight ratio should be appreciably higher than the 6 lb/gal value that the earlier laboratory tests had indicated to be optimum. A set of recommended weight ratios for the several combinations of wastes and solids mixes was prepared.

4.1.4 Well Plugging

The existing slot in the injection well (at 842 ft) was plugged with cement.

4.1.5 Well Slotting

The well was slotted at 832 ft. The fracturing pressure, 6000 psi, was unusually high. Airborne radioactivity at the top of the wellhead cell was measured during the slotting operation. No alpha emissions were detected, whereas the beta-gamma emission level was 2.7×10^{-12} μCi/cc. This is about 0.3% of the ^{90}Sr concentration guide for a controlled area, if we assume that all the emissions were due to ^{90}Sr (which is very improbable).

Radiation doses received during the slotting operation ranged from 38 to 80 mR for the five men involved; the average was 50 mR. In general, well slotting does not contribute significantly to radiation exposure.

4.2 Description of Injection

The injection was started at 10:30 on September 29. Contaminated water from the waste pit was mixed with solids from bin 4 at the recommended density of 11.1 lb/gal. After 30 min of smooth operation, the flow was switched to waste solution from T-3 and the solids flow rate was increased

in order to increase the slurry density to about 11.7 lb/gal. Almost immediately thereafter, the waste flowmeter stopped functioning. Since there is considerable redundancy in the instrumentation, the injection was continued with the flowmeter inoperative; during the period that followed, the flow rates were determined as needed from the stroke counter of the injection pump and the changes in levels of the waste tanks.

At 1200 an operator error caused depletion of the air supply to the injection pump and consequent loss of control. A brief shutdown (< 5 min) was required to remedy this situation.

At 1305 it was noted that the flow through the Densometers was inadequate. The hydraulic pump that powers the Densometer pump was checked to determine the source of this problem, and a strainer was found to be plugged. The strainer was subsequently cleaned, and the pump was returned to service.

At 1720 the quantity of solids remaining was judged to be sufficient for about 10 min of further operation, and the liquid flow was switched to water. At 1735 the supply of solids was entirely consumed, and the injection was stopped. Then the injection well was overflushed with 840 gal of water and valved shut. Finally, the facility was washed.

The fracturing pressure and injection pressure throughout the run were abnormally high — about 1000 psi higher than in previous injections. Plots of the injection pressure and slurry flow rate are given in Fig. 8. There is no apparent correlation between these two parameters. The reason for the high pressure is not known. No difficulties were encountered in blending the solids and waste; no gelling of grout in the sump tub was noted, and the grout remained fluid and uniform throughout the run. The unchanged appearance of the grout in the sump tub while each solids bin was being emptied indicated that there were no major variations in the composition of the blended solids. In contrast to reports of earlier injections, no change in grout properties was observed as the dregs of each waste tank were emptied.

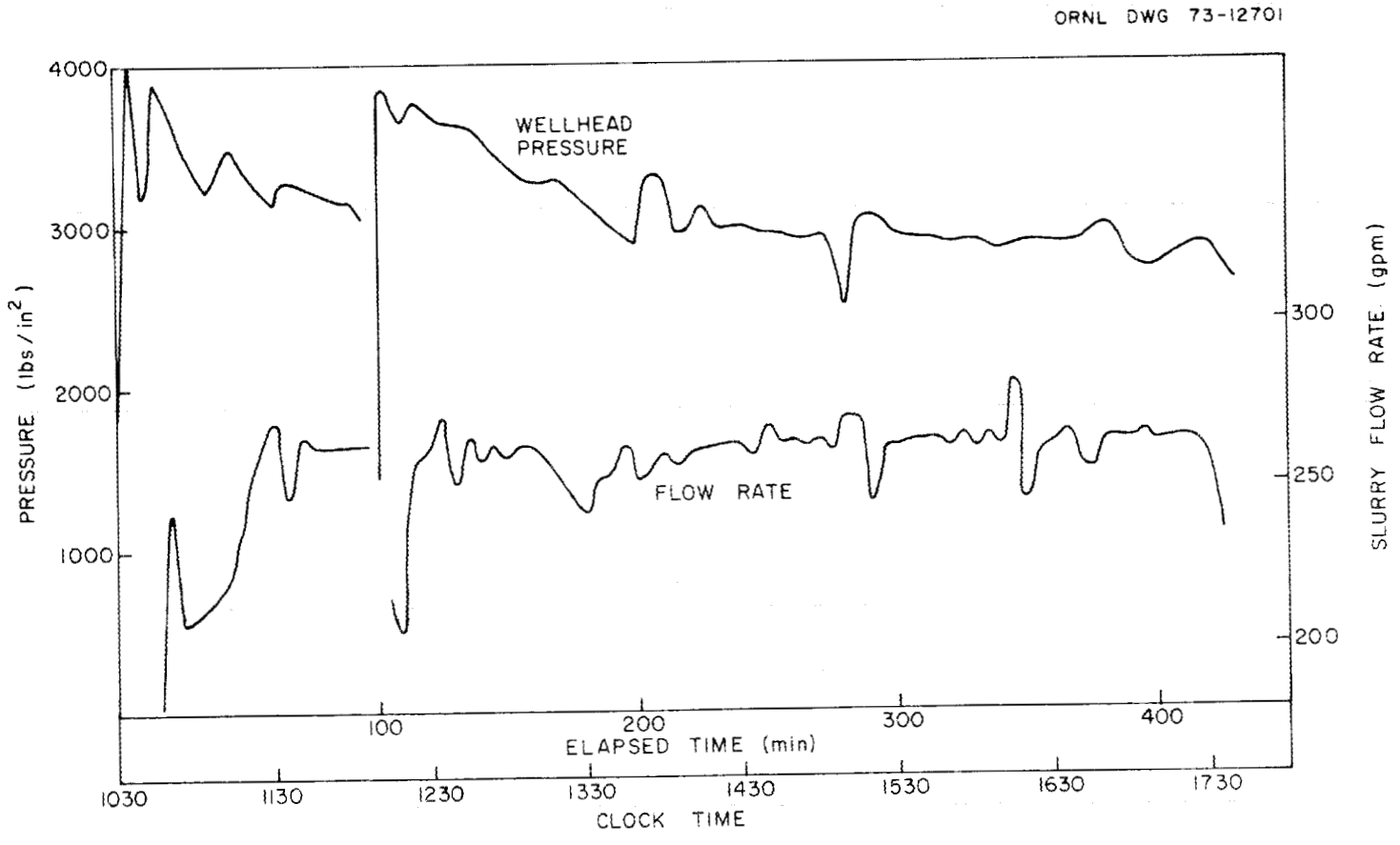

Fig. 8. Wellhead Pressure (Annulus) and Slurry Flow Rate During Injection ILW-8.

4.3 Data Analysis

Data collected during the injection is shown in Fig. 9 (the Densometer readings), Fig. 10 (the mass-flowmeter readings), Fig. 11 (the indicated waste tank levels), and Fig. 12 (the stroke-counter readings). Since there are discrepancies in the data, the initial problem is to decide which instrument readings are most reliable.

A brief examination of Fig. 11 indicates that the waste-tank level readings are seriously in error. A sudden decrease in the indicated level of T-3 occurred during the injection, and large differences in T-2, T-4, and T-9 were noted between the initial indicated volumes (read before the injection) and the first volume read during the injection. These discrepancies cumulatively amount to several thousand gallons and make such readings unusable for calculational purposes.

The stroke-counter readings seem reliable and consistent.

The mass-flowmeter readings indicated a total solids consumption of 660,000 lb — 64,000 lb more than was on hand at the start of the injection. A correction must be made for this error, which was the result of a buildup of a layer of solids on the instrument sensing cone. It was assumed that the instrument was reading accurately during the first 30 min of operation and that the error was constant throughout the subsequent run time. A corrected mass flow rate was calculated based on these assumptions; this corrected rate is also shown in Fig. 10. The calculated correction amounts to 50 lb/min.

The Densometer readings are inaccurate. Laboratory mix data can be used to determine solids/liquid weight ratios that correspond to the slurry density at various times during the injection. If this is done, a weight ratio averaging less than 6 lb/gal is calculated; the weight ratio must be more than 7 lb/gal to account for all the solids that were used in the injection.

The most reliable data appeared to be the stroke-counter readings and the corrected mass-flowmeter readings. Therefore, these readings were used to calculate the probable waste volumes and weight ratios for the various stages of the injection (see Table 2). The calculated values obtained for the weight ratios during the injection are generally close

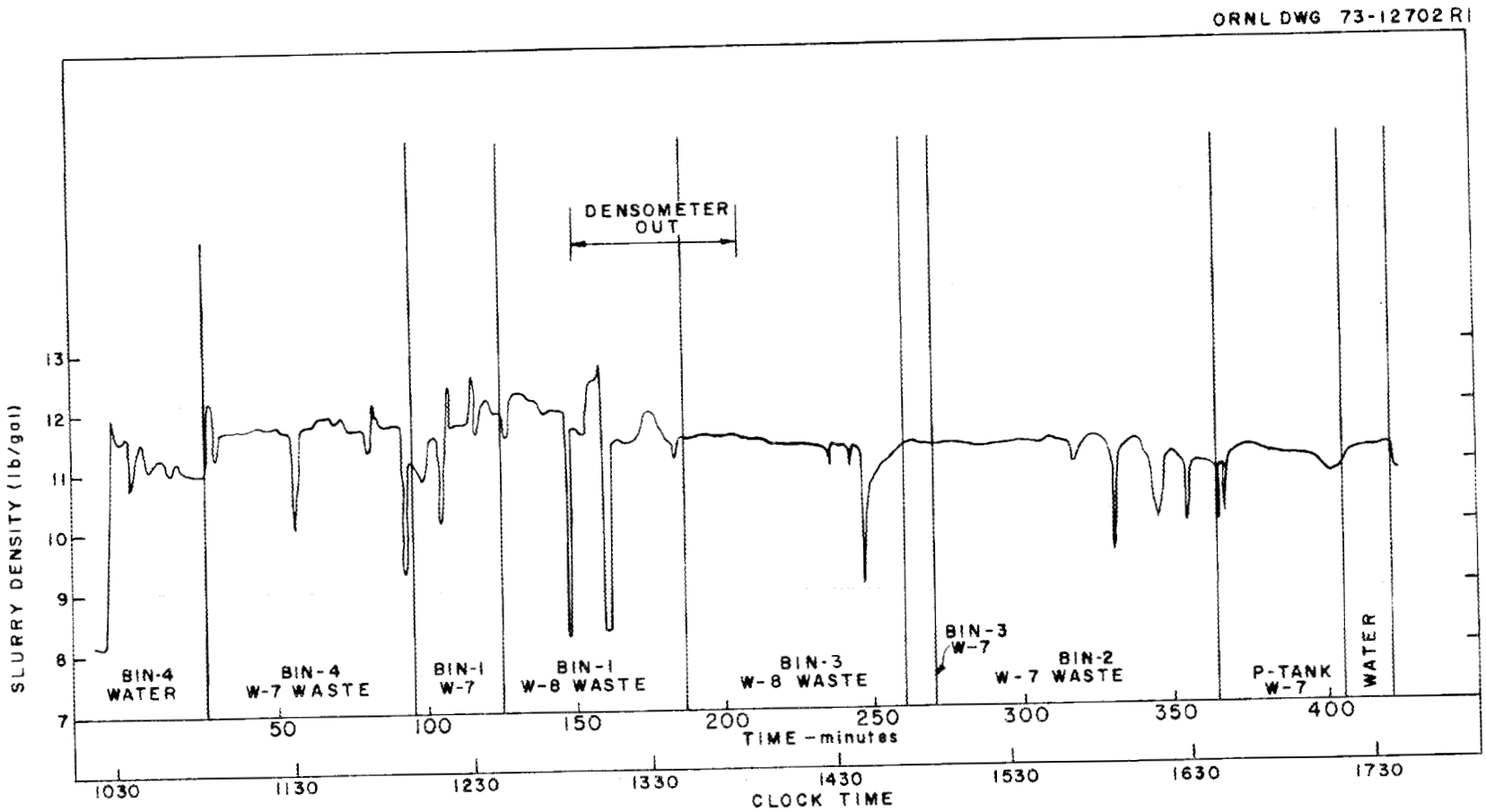

Fig. 9. Slurry Density During Injection ILW-8.

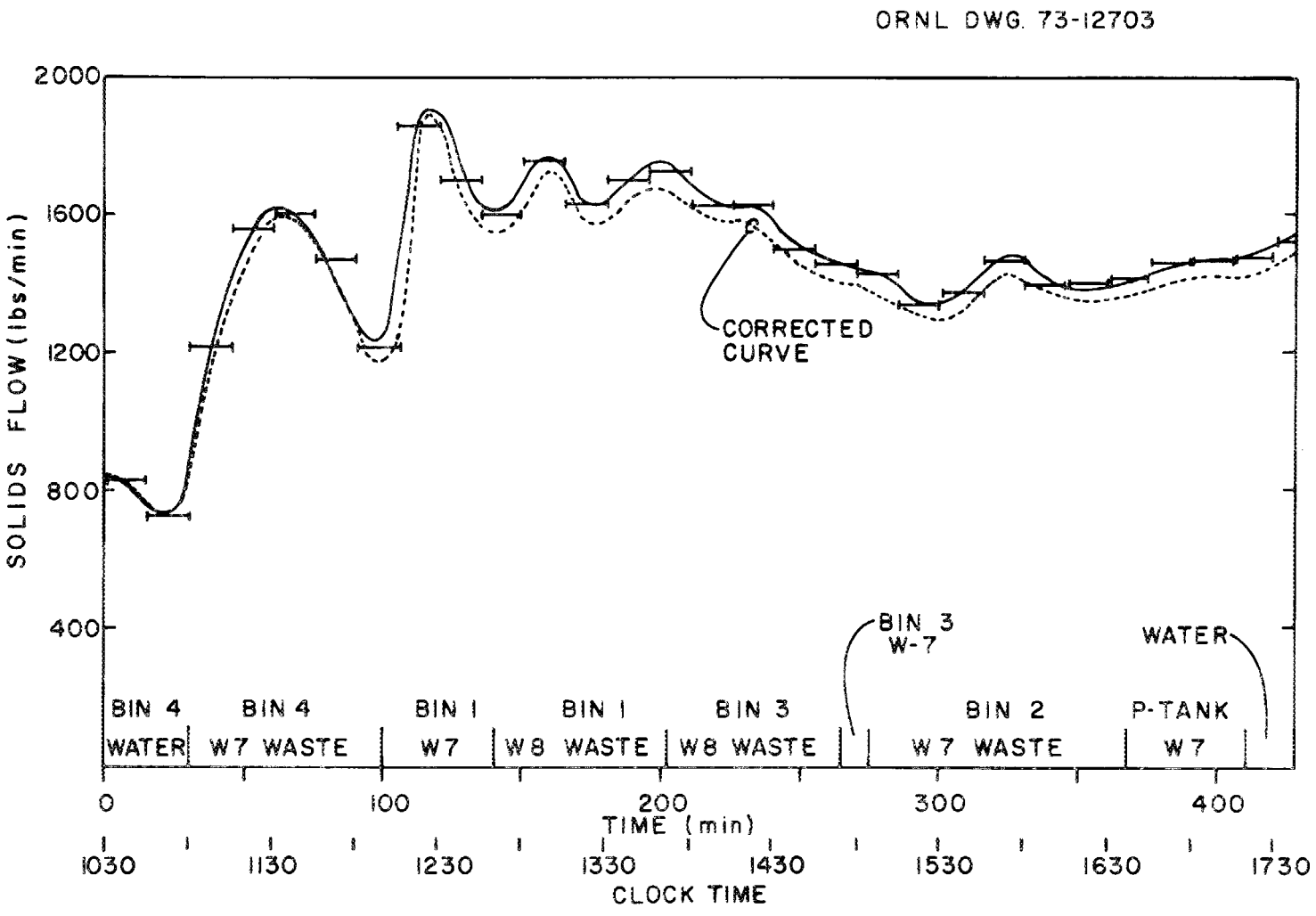

Fig. 10. Mass Flowmeter Reading During Injection ILW-8.

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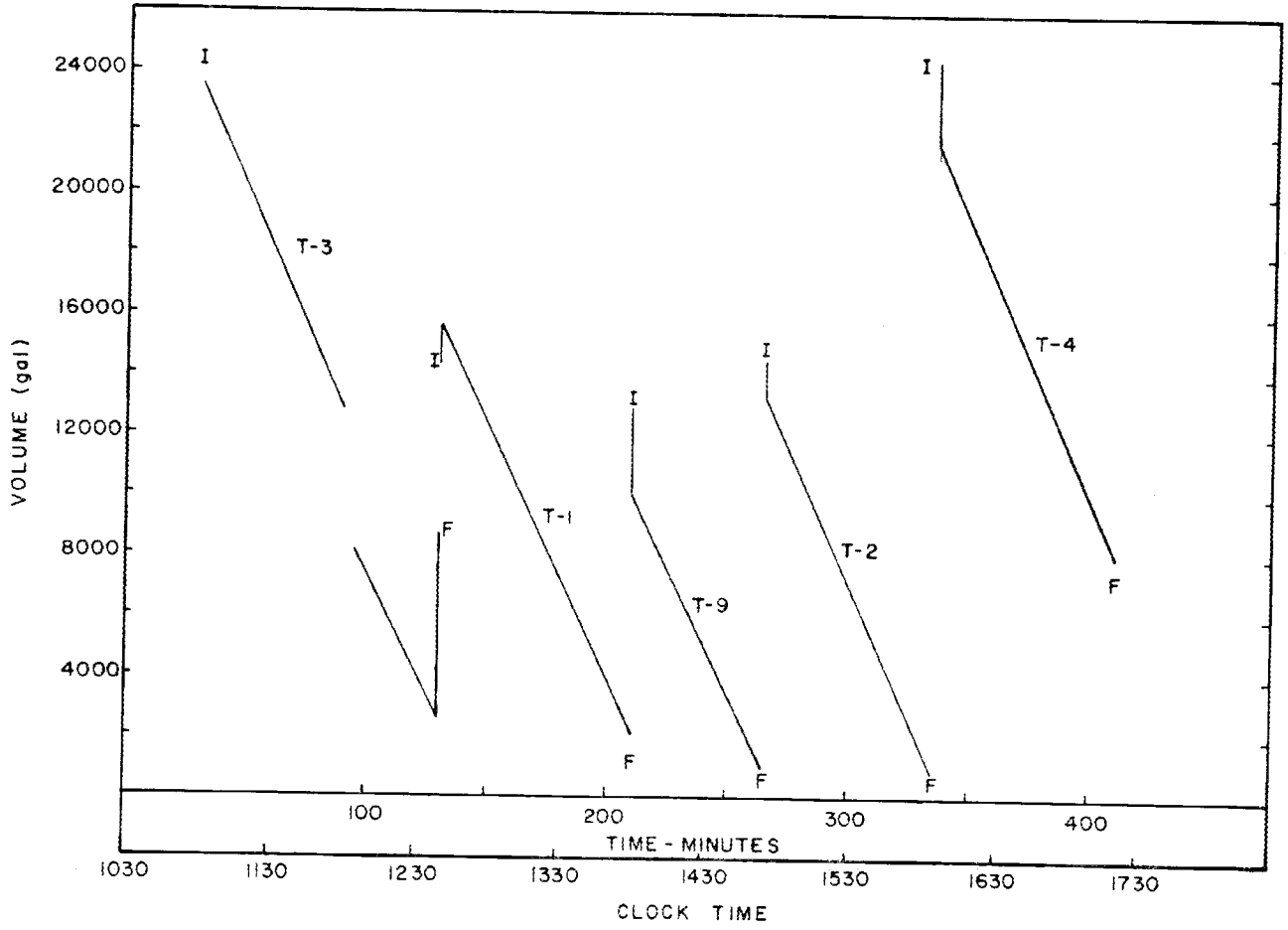

Fig. 11. Indicated Waste Tank Levels During Injection ILW-8
I - Initial Indicated Volume; F - Final Indicated Volume.

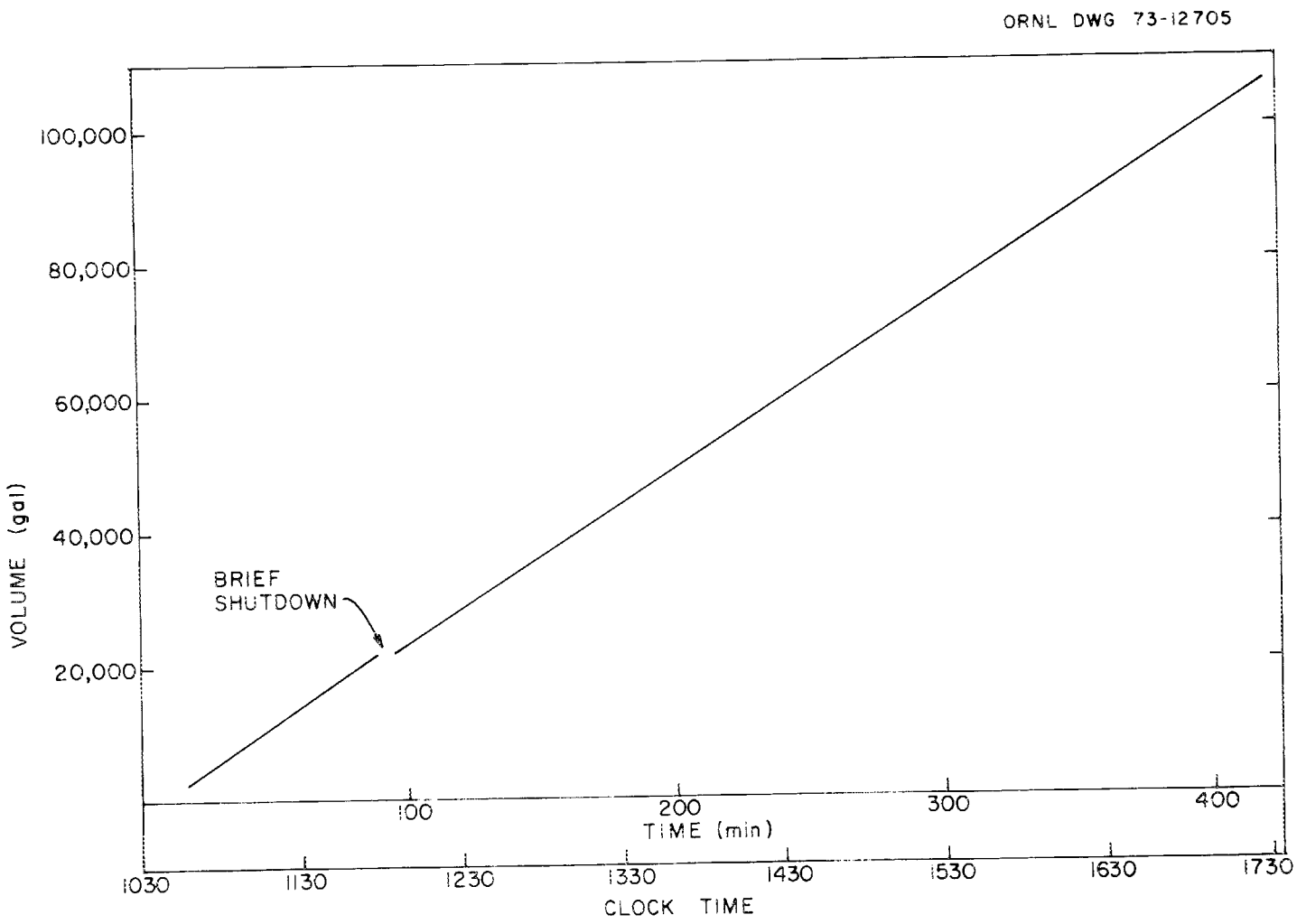

Fig. 12. Stroke Counter Reading During Injection ILW-8.

Table 2. Calculated Mix Ratios for Injection ILW-8

Clock Time		Net Time			Grout Flow	Corrected Totalizer Reading	Calculated Values		Waste Flow	Waste Flow	Estimated Phase Separation	
From	To	(min)	Solution	Bin	(gal)	(lb/min)	Solids Consumed (lb)	Weight Ratio (lb/gal)	(gpm)	(gal)	%	gal
1030	1100	30	Water	4	6,500	870	26,100	5.05	172	5,160	7	500
1100	1210	70	W-7 waste	4	16,920	1370	95,800	7.15	192	13,400	0	0
1210	1240	30	W-7 waste	1	7,580	1600	48,000	8.7	184	5,520	0.5	150
1240	1342	62	W-8 waste	1	15,940	1610	100,000	8.75	184	11,400	0	0
1342	1455	73	W-8 waste	3	19,060	1480	108,000	7.85	189	13,750	1	190
1455	1505	10	W-7 waste	3	2,500	1340	13,400	6.9	194	1,940	12	300
1505	1638	93	W-7 waste	2	24,500	1310	122,000	6.7	197	18,300	1.5	370
1638	1720	42	W-7 waste	P-tank	11,000	1350	56,800	6.75	200	8,400	1.5	165
1720	1737	17	Water	P-tank	4,605	1420	24,200	7.5	189	3,200	0	0

to the recommended ratios, and the estimated values for anticipated phase separation are correspondingly low.

4.4 Radiation Doses Received

The radiation exposures received by Halliburton personnel are listed in Table 3. These exposures were predominantly received during maintenance operations prior to the injection; only a small fraction was received during the injection and subsequent washup operations.

Airborne radioactivity during the injection was monitored at two locations: in the operating area, and on top of the mixer cell. In the operating area the average beta-gamma emission level was 1.4×10^{-11} μCi/cc; the alpha level was zero during most of the run and averaged 9.2×10^{-14} μCi/cc during the last 2 hours. The corresponding emission levels above the mixer cell were 1.3×10^{-10} μCi/cc and 1.7×10^{-12} μCi/cc. The ^{90}Sr, ^{244}Cm, and ^{137}Cs concentration guides for a controlled area are 1×10^{-9}, 9×10^{-12}, and 6×10^{-8} μCi/cc, respectively. The measured activities were well below these values.

5. INJECTION ILW-9

5.1 Preliminary Preparations

5.1.1 Facility Maintenance

The waste flowmeter was removed from the waste line, and a piece of pipe scale that was found to be jamming the turbine blade was removed. The flowmeter was subsequently reinstalled. A check of the waste-tank level indicator system showed that the cause of the difficulty in this system was a partially plugged vent filter. After the filter had been replaced and a new one installed, the level indicators were found to work properly.

A slight leak from one of the Gadco dampeners on the injection pump had been observed during the first injection. Therefore, this dampener was removed, inspected, and reinstalled with fresh thread sealer. The pump packing was tightened, the diaphragm of the pressure relief valve was replaced, the high-pressure shutoff valves were checked, and the Densometers were checked and calibrated.

Table 3. Radiation Exposures Received by Halliburton Personnel During Injection ILW-8

Job Description	Total Exposure (mR)	Maintenance Exposure		Slotting Exposure		Injection Exposure	
		mR	% of Total	mR	% of Total	mR	% of Total
Cementer	370	289	78	11	3	70	19
Cementer	400	280	70	80	20	40	10
Mechanic	390	320	82	43	11	27	7
Mechanic	260	231	89	8	3	21	8
Mechanic	320	260	81	38	12	22	7
Instrument mechanic	110	41	37	41	37	28	26
Instrument mechanic	90	60	67			30	33
Supervisor	80	56	70	2	3	22	27
Supervisor	230	173	75	50	22	7	3
Supervisor	40	16	40			24	60

5.1.2 Blending of Solids

Three loads of solids were blended during the week of October 2, and two loads during the week of October 9. A total of 593,490 lb of solids was blended and stored as follows:

Container	Weight (lb)	Date
Bin 1	121,410	3 October
Bin 2	114,900	9 October
Bin 3	127,330	2 October
Bin 4	119,460	4 October
P-1 tank	36,700	10 October
P-2 tank	36,790	10 October
Scale tank	36,900	10 October

5.1.3 Waste Transfer

Waste solution was pumped to the site and distributed as follows:

T-1	14,170 gal
T-2	14,179 gal
T-3	23,481 gal
T-4	23,679 gal
T-9	12,433 gal

5.1.4 Formation Breakdown

The existing fracture at 832 ft was reopened by pumping 3000 gal of water at a pressure of 3600 psi. This volume of water was considerably in excess of requirements.

5.1.5 Compatibility of Waste and Solids Mix

The waste solution to be disposed of in Injection ILW-9 was the remaining waste in tank W-7. The analysis of this solution is given in Table 1. The solids mix used was the same as that used in Injection ILW-8.

After the solids required for the injection had been blended and stored in the four bulk storage bins and the blending tanks, a sample was taken of the solids at the top of each bulk bin and the top of the third blending tank. These samples were mixed with synthetic waste solution at various solids/waste weight ratios, and the density and the phase separation of the resulting grouts were determined. The results of these determinations were quite similar to those observed during earlier tests, made prior to Injection ILW-8, with plant-blended solids (see Sect. 6). In each

case the observed phase separation varied appreciably from bin to bin, with the solids blend in one bin having a particularly high phase separation; also, the field-mixed solids blends yielded a grout with a much higher phase separation than did the laboratory-mixed solids blends. The possibility that the field-mixed solids were inadequately blended was checked by testing samples taken from the top, middle, and bottom of bin 4. For a weight ratio of 7 lb/gal, the phase separations obtained from these three samples were 8.4%, 8.3%, and 3.8%, respectively. The low value for the last sample can probably be explained by noting that the bottom of the bin contained a residue of solids from the previous injection and at least some of this residue mixed with the sample. Another possible cause of the observed variation in grout properties is day-to-day differences in cement composition. A preliminary check of this possibility was made by comparing the phase separation obtained from a field-mixed solids blend with the phase separation obtained from a laboratory-mixed solids blend made from the identical truck load of cement. The laboratory-mixed solids blend gave results similar to those obtained with almost all other laboratory mixes — a phase separation of about 1% at a weight ratio of 6 lb/gal. The field-mixed solids blend gave results similar to those obtained with the best-quality field mixes — a phase separation of about 5% at a weight ratio of 6 lb/gal. Although this single result does not rule out the possibility of cement variations, some additional factor is likely also present.

A set of recommended weight ratios for the several combinations of waste and solid mixes and water was prepared.

5.2 Description of Injection

Injection ILW-9 was started at 8:56 on October 17. Fresh water was mixed with solids from bin 3 during the first few minutes of the injections so that the operability of the facility could be established with nonradioactive solution. After 7 min of operation, the water was shut off and the waste solution was pumped from T-1.

At 1544 the liquid flow was switched to the waste pit, and about 4000 gal of contaminated water was mixed with solids and pumped down the well.

At 1607 the quantity of solids remaining was judged to be sufficient for about 10 minutes of operation, and the liquid flow was switched to fresh water.

At 1620 the supply of solids was found to be entirely consumed, and the injection was stopped. The injection well was then overflushed with 800 gal of water and valved shut. Finally, the facility was washed.

As in Injection ILW-8, the injection pressure throughout this injection was unusually high. Plots of the injection pressure and the slurry flow rate are shown in Fig. 13.

The only equipment malfunction experienced during this injection was a Densometer pump seal failure, which occurred near the end of the injection. The blending of the solids and the waste solution was accomplished with no difficulty except for one short period when the grout thickened and became difficult to pump. The solids weight ratio was reduced briefly, and the grout became fluid and pumpable. The reason for this brief difficulty is not known; it did not correspond to a low waste tank level or a particularly high average solids flow. A momentarily high, instantaneous solids flow is perhaps the best explanation. More difficulty than usual was encountered in getting the solids to flow from the bulk storage bins when each was initially put on stream. As in Injection ILW-8, the unchanged appearance of the grout in the sump tub throughout the emptying of each bin indicated that there were no major variations in the composition of the blended solids.

5.3 Data Analysis

Some of the data collected during the injections are shown in Fig. 14 (the Densometer readings), Fig. 15 (the waste flow rate), and Fig. 16 (the solids flow rate). Values for the waste flow rate are taken from the flowmeter totalizer; values for the solids flow rate are taken from the mass-flowmeter totalizer.

A comparison of the waste tank level readings with the flowmeter totalizer readings indicates good agreement; the flowmeter totalizer figures are consistently about 4% higher than those for the waste tank level. This is not a significant difference for such an operation.

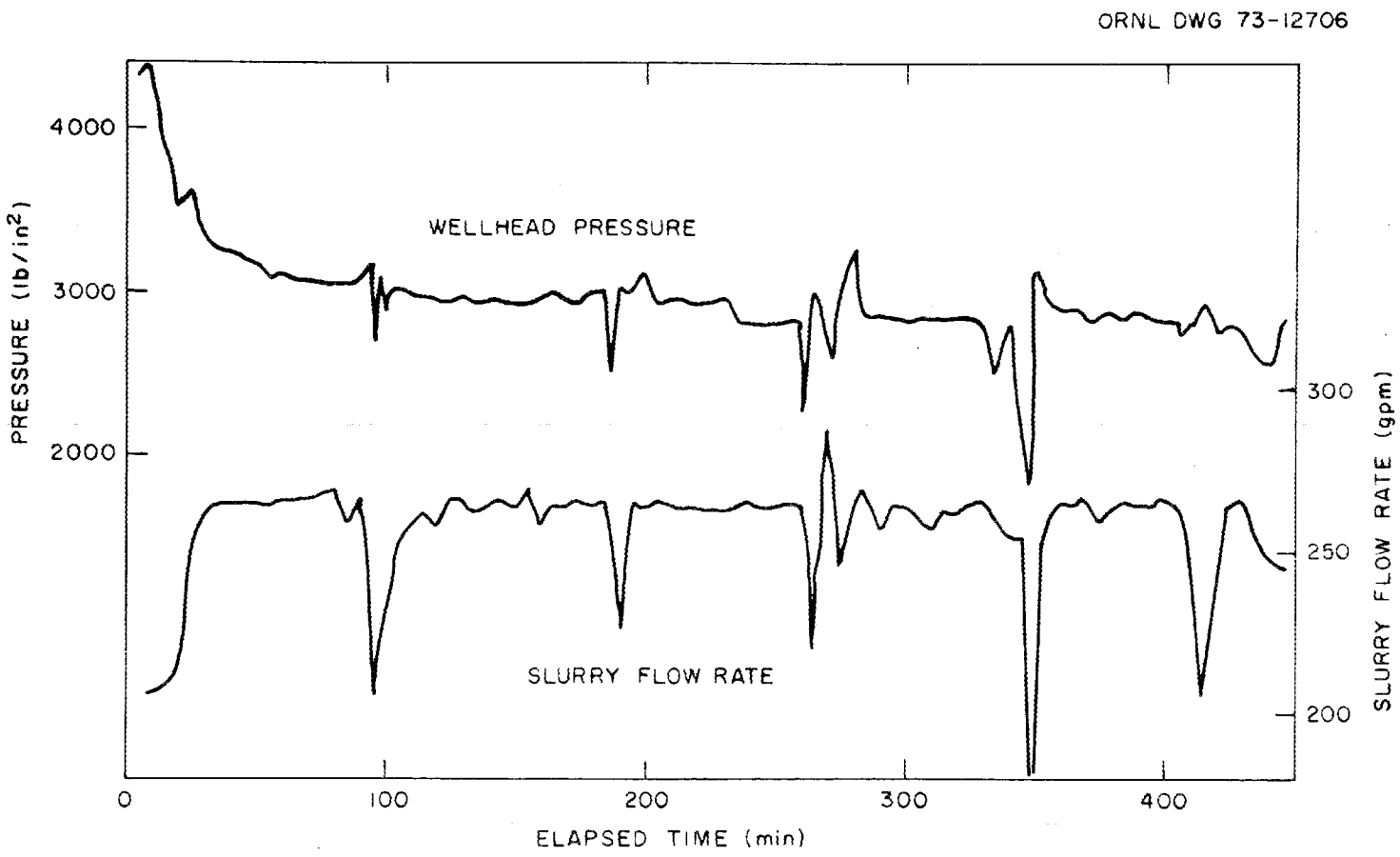

Fig. 13. Wellhead Pressure (Annulus) and Slurry Flow Rate During Injection ILW-9.

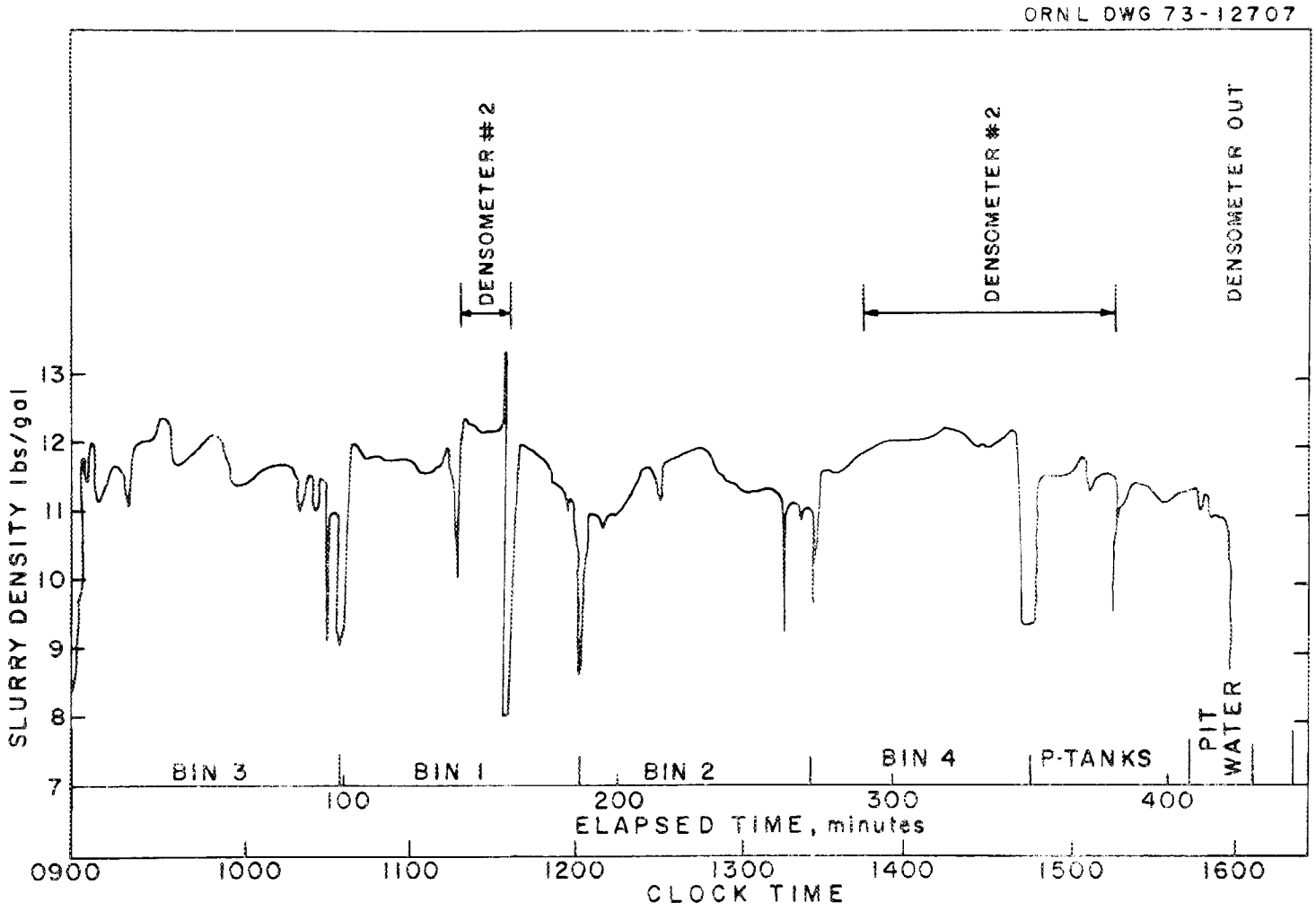

Fig. 14. Slurry Density During Injection ILW-9.

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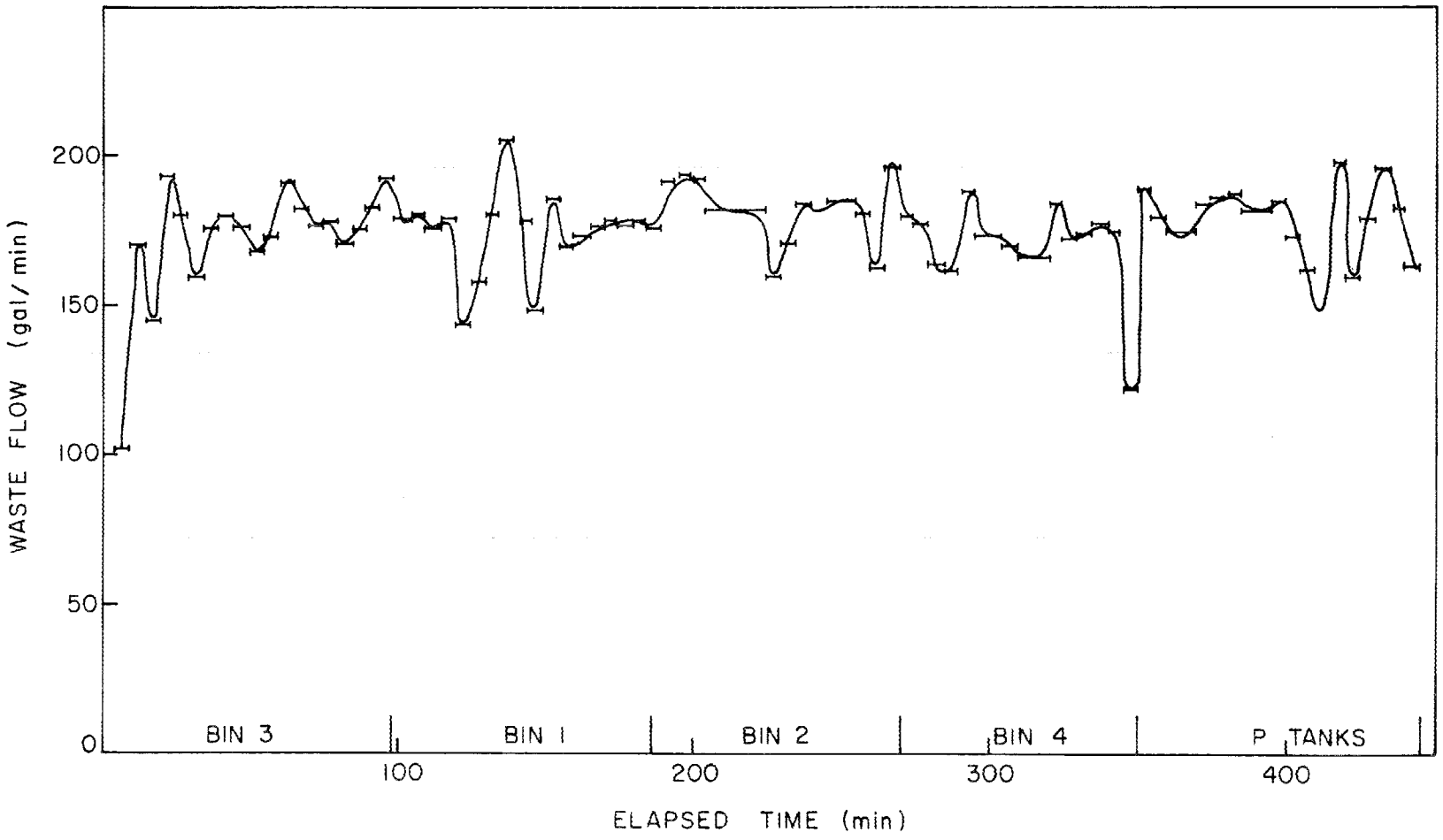

Fig. 15. Waste Flow Rate, as Determined by Flowmeter Totalizer, During Injection ILW-9.

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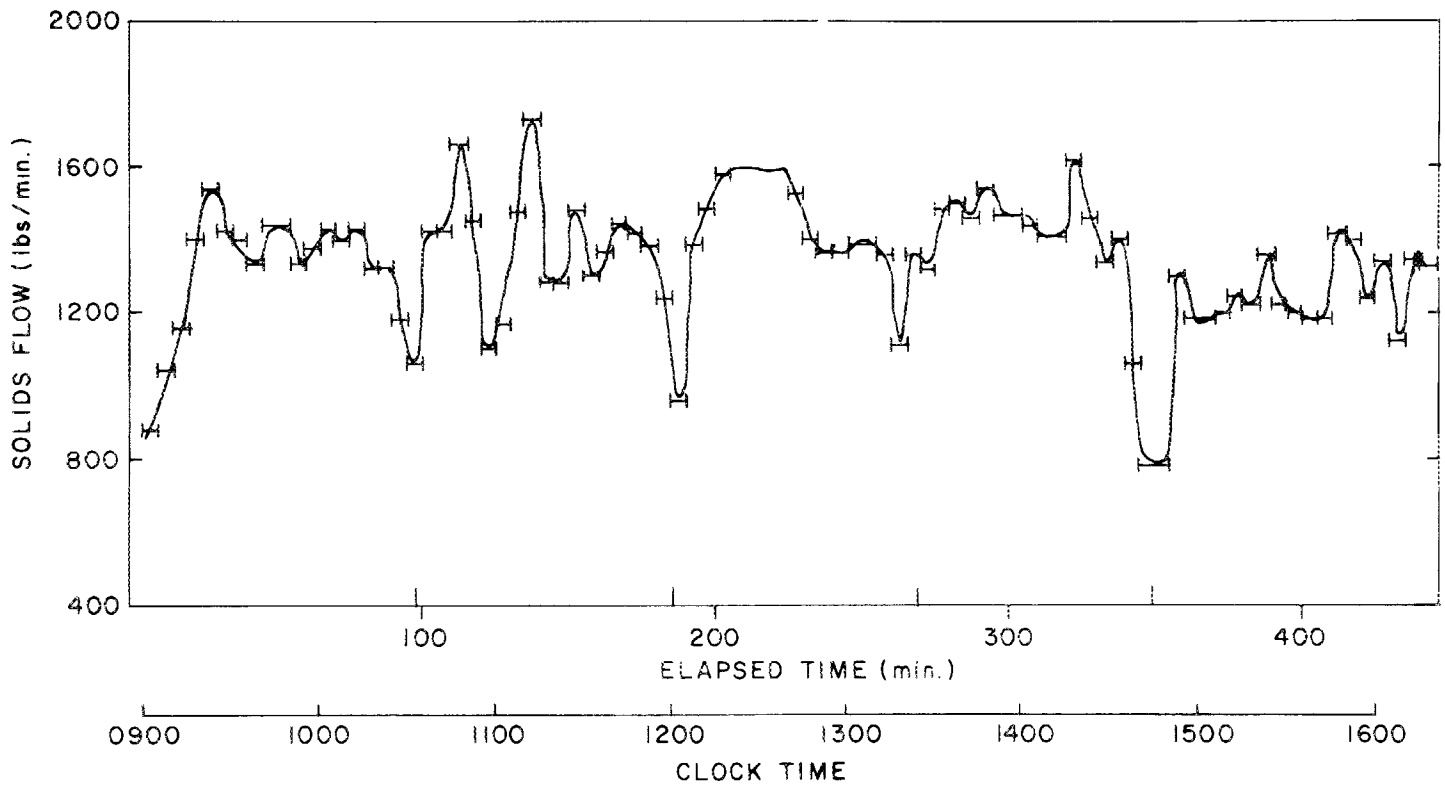

Fig. 16. Solids Flows Rate (from Mass Flowmeter Totalizer).

The mass-flowmeter readings indicate a total solids consumption of 596,560 lb. This number is in good agreement with the quantity of solids that was on hand at the start of the injection (i.e., 593,500 lb). No correction to the mass flowmeter readings was made for this run.

Again, as in Injection ILW-8, the Densometer readings are inaccurate. If the slurry densities indicated by the Densometers are used to calculate the solids weight ratios for various times during the injection, less than 75% of the total solids consumed can be accounted for. An error of 2 lb/gal in the weight ratio, or 0.7 lb/gal in the Densometer, must be assumed to account for such a discrepancy. The error for Densometer 2 was apparently smaller than that for Densometer 1; during the times that Densometer 2 was being operated, the error in weight ratio was likely less than 1 lb/gal.

The solids flow rate indicated by the mass flowmeter, divided by the liquid flow rate, gives the weight-ratio curve shown in Fig. 17. This curve shows the fluctuations in the weight ratio that occur during an injection; they are generally within 1/2 lb/gal of the average but occasionally in excess of 1 lb/gal. Many of the large deviations occurred when the solids flow was switched between bins and were caused by the difficulty in obtaining a prompt flow of solids.

The calculated injection parameters are summarized in Table 4. The average weight ratios of the grout injected at various times are generally close to the recommended ratios, and the estimated values for anticipated phase separation are correspondingly low. These anticipated phase separation numbers do not allow for water not completely bled back after Injection ILW-8 or the excessive volume of water that was injected to open the fracture prior to Injection ILW-9.

5.4 Radiation Doses Received

The radiation exposures received by Halliburton personnel during Injection ILW-9 are listed in Table 5. These exposures are reduced by approximately one-half from those received in Injection ILW-8 because of the reduced maintenance that was required and because no slotting operation was performed. The exposure received during the injection itself is virtually identical to that received during Injection ILW-8.

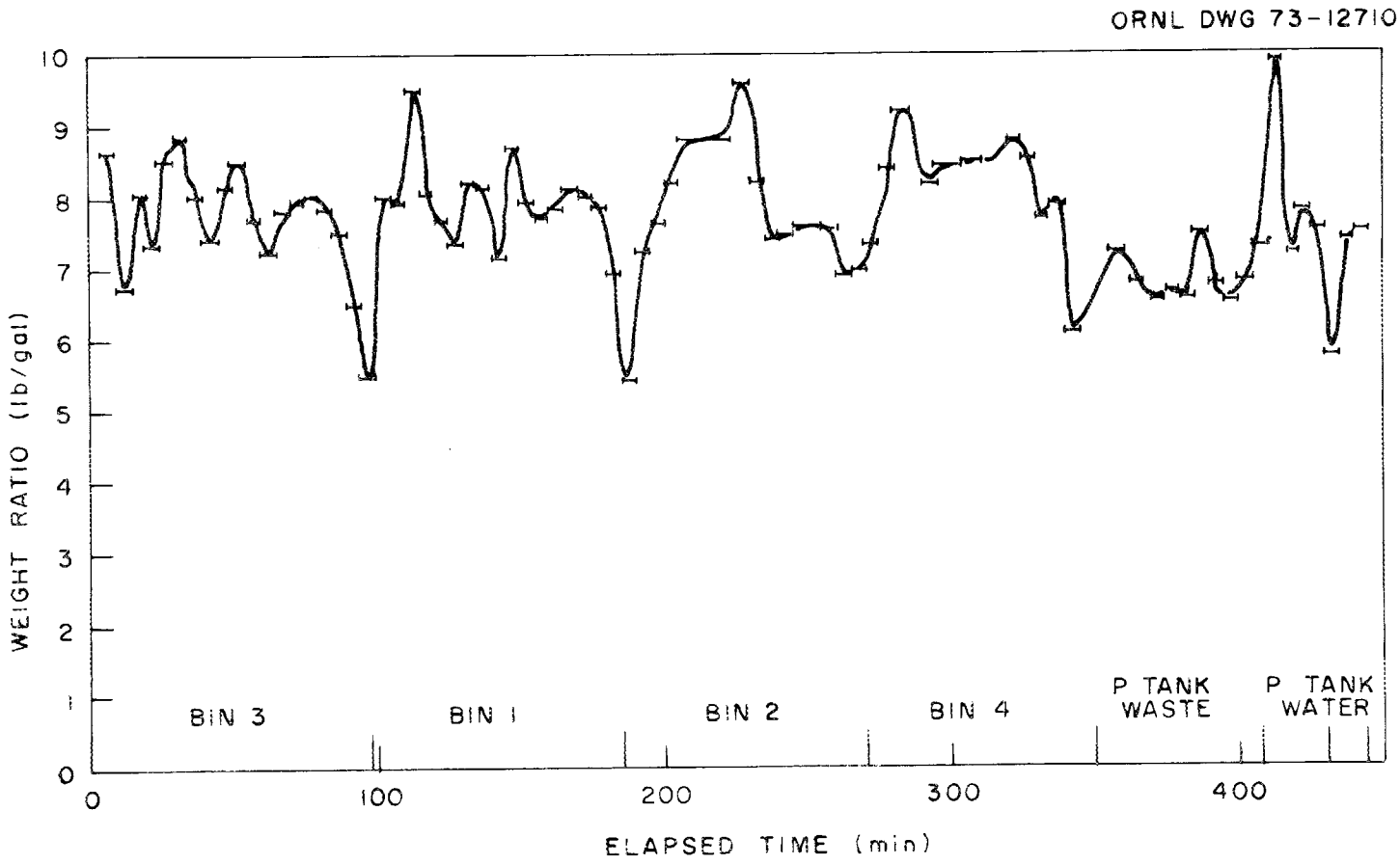

Fig. 17. Weight Ratios During Injection ILW-9.

Table 4. Calculated Parameters for Injection ILW-9

Clock Time From	Clock Time To	Elapsed Time (min)	Solution	Bin	Waste Flow (gal)	Densometer Reading (lb/gal)	Wt. Ratio Calculated from Densometer Reading (lb/gal)	Solids Consumed (lb/min)	Solids Consumed (lb)	Weight Ratio (lb/gal)	Estimated Phase Separation %	Estimated Phase Separation gal
0856	0903	7	Water	3	1,130	10.6	4.5	570	4,000	3.5	20	290
0903	1034	91	Waste	3	15,200	11.6	6.25	1,370	125,000	8.2	0.2	46
1034	1202	88	Waste	1	15,000	11.7	6.0	1,370	120,400	8.0	0.8	185
1202	1326	84	Waste	2	14,800	11.4	5.0	1,410	118,250	8.0	0.8	175
1326	1445	79	Waste	4	13,200	11.95	6.7	1,410	111,710	8.45	2.0	400
1445	1544	59	Waste	P-tank	10,100	11.5	5.3	1,160	68,490	6.8	1.8	280
1544	1607	23	Pit water	P-tank	3,940	11.0	5.1	1,360	31,340	8.0	3.0	140
1607	1620	13	Water	P-tank	2,300	-	-	1,390	18,070	7.9	3.0	105

Table 5. Radiation Exposures Received by Halliburton Personnel During Injection ILW-9

Job Description	Total Exposure (mR)	Maintenance Exposure		Injection Exposure	
		mR	% of Total	mR	% of Total
Cementer	190	161	85	29	15
Cementer	190	161	85	29	15
Mechanic	190	171	90	19	10
Mechanic	70	25	35	45	65
Mechanic	100	90	90	10	10
Instrument mechanic	20	10	50	10	50
Supervisor	30	6	20	24	80
Supervisor	30	13	45	17	55

Airborne radioactivity during the injection was monitored in the operating area and on top of the mixer cell. The detected activity was low in each location. The average beta-gamma and alpha concentrations on top of the cell were 1.6×10^{-9} μCi/cc and 1×10^{-13} μCi/cc, respectively. The corresponding values for the operating area were 2×10^{-12} μCi/cc and 4×10^{-14} μCi/cc.

6. INJECTION ILW-10

6.1 Preliminary Preparations

6.1.1 Facility Maintenance

The injection pump was repacked, and the plungers were replaced. The mass flowmeter was found to be jammed by cement dust that had entered through a small opening. It thus became necessary to remove this instrument from the cell so that repairs could be made.

During the preinjection pressure testing of the high-pressure piping manifold, one of the Gadco dampeners that was mounted on the injection pump was blown off its fitting. The injection pump was promptly stopped, and the pump cell was washed down to flush out the contaminated pit water that had been sprayed into the cell. After the dampener had been removed from the cell, a plug was installed on the injection pump and testing of the high-pressure piping was resumed. All valves were tested to 5000 psi; the pressure relief valve was adjusted and tested to 7500 psi.

Examination of the Gadco dampener indicated that a crack in the threaded joint had likely been present for some time and that this crack had probably propagated when the system was subjected to the pressure surges that are incident to preinjection testing. This dampener had been observed to be leaking during Injection ILW-8. It was assumed at the time that the seal was faulty; hence, the dampener was removed and new thread tape was applied. The dampener was reinstalled prior to Injection ILW-9.

6.1.2 Blending of Solids

Five loads of solids were blended during the week of October 23; one load was blended on October 30. A total of 677,880 lb of solids was blended

and stored as indicated in Table 6. One load was divided between Bins 3 and 4; therefore, the weight of solids in each of these bins is not known with precision. However, the total of the two bins is correct.

Table 6. Distribution of Blended Solids for Injection ILW-10

Container	Blending Date	Weight (lb)	Total in Bin (lb)
4	October 23	108,550	128,350
4	October 24	19,800[a]	
3	October 24	102,830[a]	139,550
3	October 25	36,720	
1	October 25	73,960	150,850
1	October 26	76,890	
2	October 26	38,610	153,710
2	October 27	81,860	
2	October 30	33,240	
P-2 tank	October 27	37,320	
P-1 tank	October 30	33,470	
Scale tank	October 30	34,630	

[a]One blended load was divided between bins 4 and 3. The division between these bins is estimated.

6.1.3 Waste Transfer

Waste solution was pumped to the site and distributed as follows:

T-1	14,881 gal
T-2	14,772 gal
T-3	24,597 gal
T-4	24,597 gal
T-9	12,947 gal

6.1.4 Formation Breakdown

The existing fracture at 832 ft was reopened by pumping 204 gal of water at a pressure of 3050 psi.

6.1.5 Compatibility of Waste and Solids Mix

Approximately 10,000 gal of W-7 waste solution remained from Injection ILW-9. However, the bulk of the waste solution to be disposed of consisted of waste from tanks W-9 and W-10. These solutions were sampled and analyzed.

The analyses, given in Table 1, indicate that the solutions in tanks W-9 and W-10 are very similar and are considerably more dilute than the W-7 waste solution.

The solids mix to be used was unchanged from that employed in the two previous injections.

The solids required for the injection were blended and stored in the four bulk storage bins, the two blending tanks, and the scale tank. A sample was taken of the solids blended on each of six days, and these samples were mixed with synthetic waste solutions at various solids/waste weight ratios. The density and phase separation of the resulting grouts were determined. The results are shown in Figs. 18 and 19. The grout properties that resulted when some of the blended solids were mixed with water and W-7 waste are shown in Fig. 20. All of these results are quite different from those observed in tests of blends from the two previous injections. At a given weight ratio of solids, the phase separations observed with the blends for Injection ILW-10 are much lower than those observed with the blends for the two earlier injections. Also, the observed "viscosities" of the ILW-10 blends were much higher. In general, the ILW-10 blends at a weight ratio of 6 lb/gal were much like the earlier blends at 8 lb/gal. Some of this difference is caused by the different waste solution used for ILW-10 (W-9 vs W-7); however, not all of the observed difference can be explained in this manner.

The reason for the observed difference in properties of grouts made from mixes blended on different days is also obscure. Since variation in cement characteristics has been suspected, samples were taken of the cement used each day. Each of these samples was blended in the laboratory with the other constituents of the solids mix and mixed with synthetic W-9 waste solution at a weight ratio of 4 lb/gal. The observed phase separations were between 0.24 and 1.8%, which is appreciably lower than any of the field blends and lower than the 6.9% phase separation obtained with bag cement (the previous standard "laboratory mix"). Although some variation in cement properties apparently occurs, it does not appear to be the reason for the range of grout properties that have been observed.

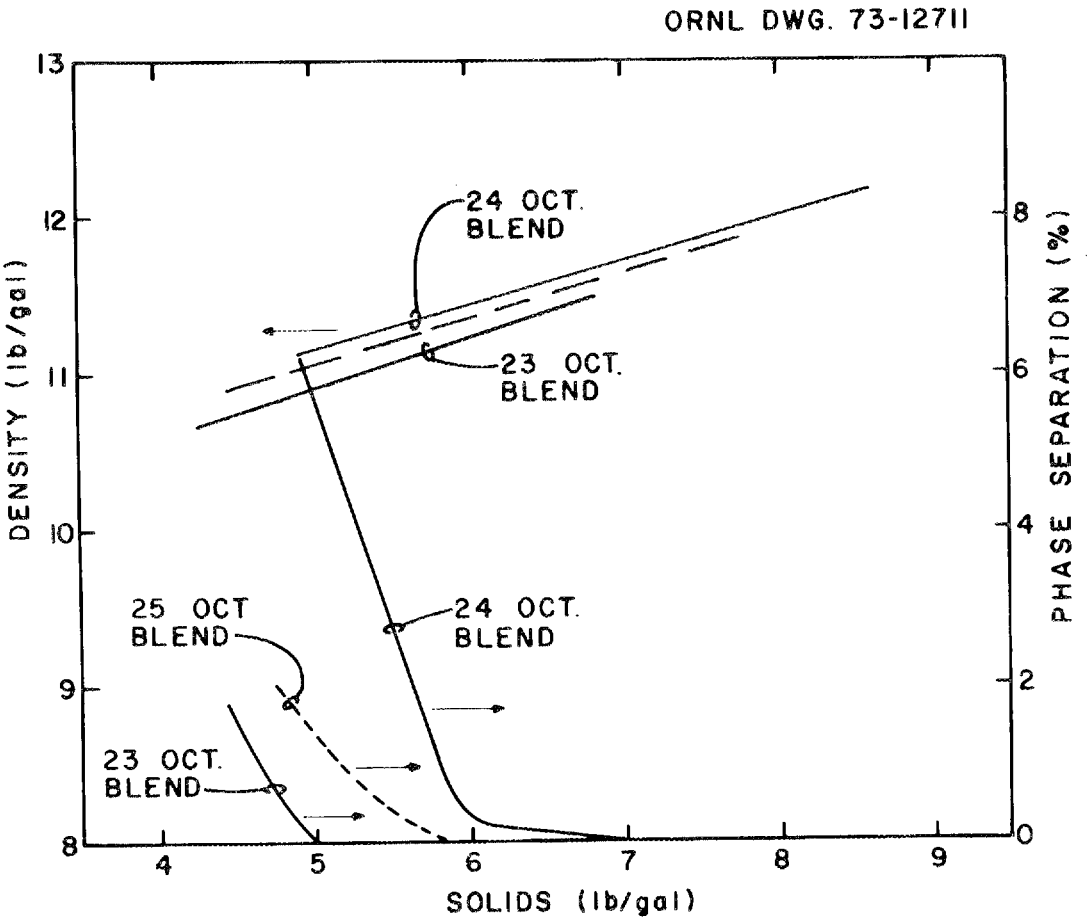

Fig. 18. Density and Phase Separation of Grout Prepared from Waste Solution W-9 and Plant-Blended Solids (October 23-25 Blends) for Use in Injection ILW-10.

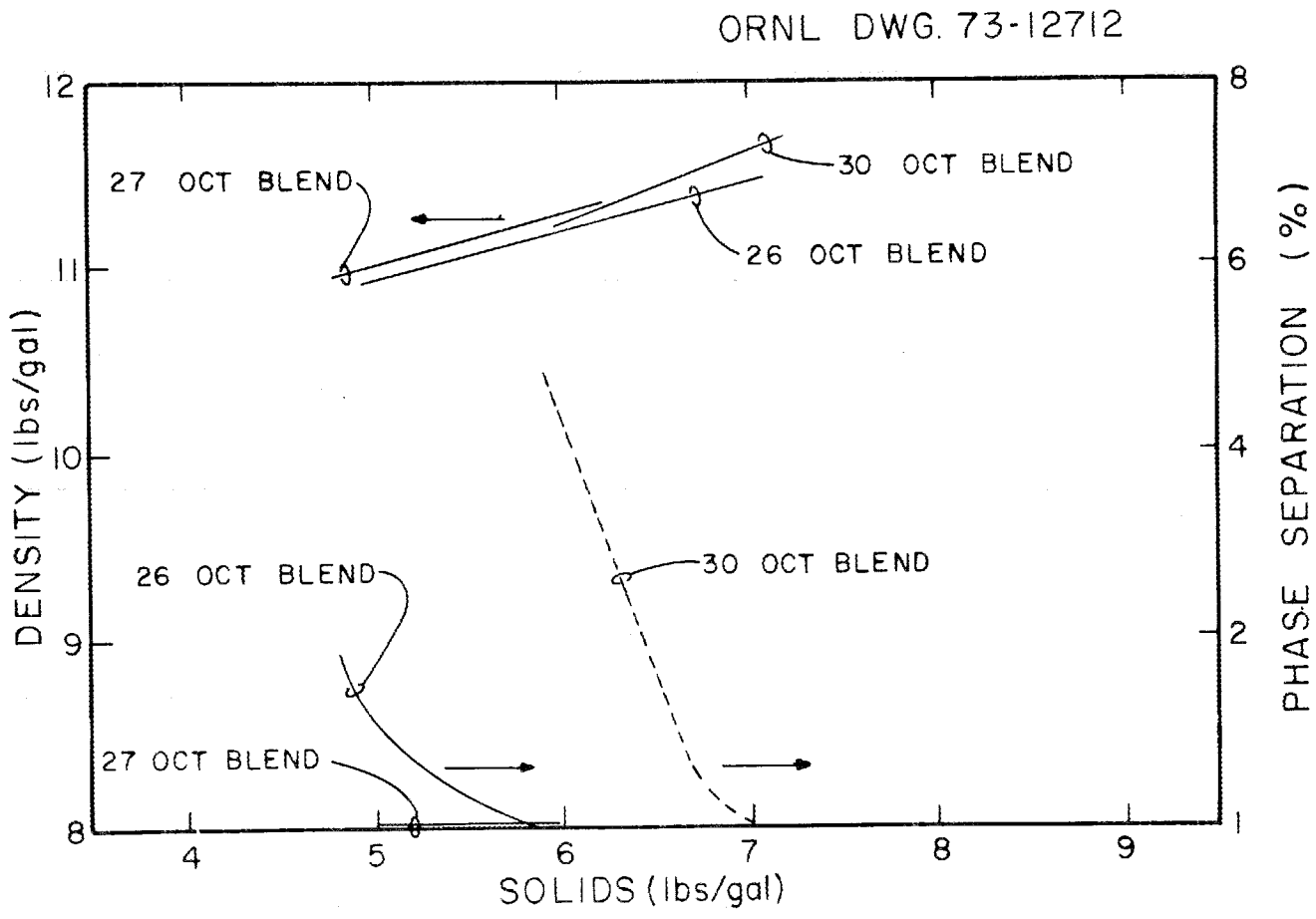

Fig. 19. Grout Density and Phase Separation of Grout Prepared from Waste Solution W-9 and Plant-Blended Solids (October 26, 27, and 30 Blends) for Use in Injection ILW-10.

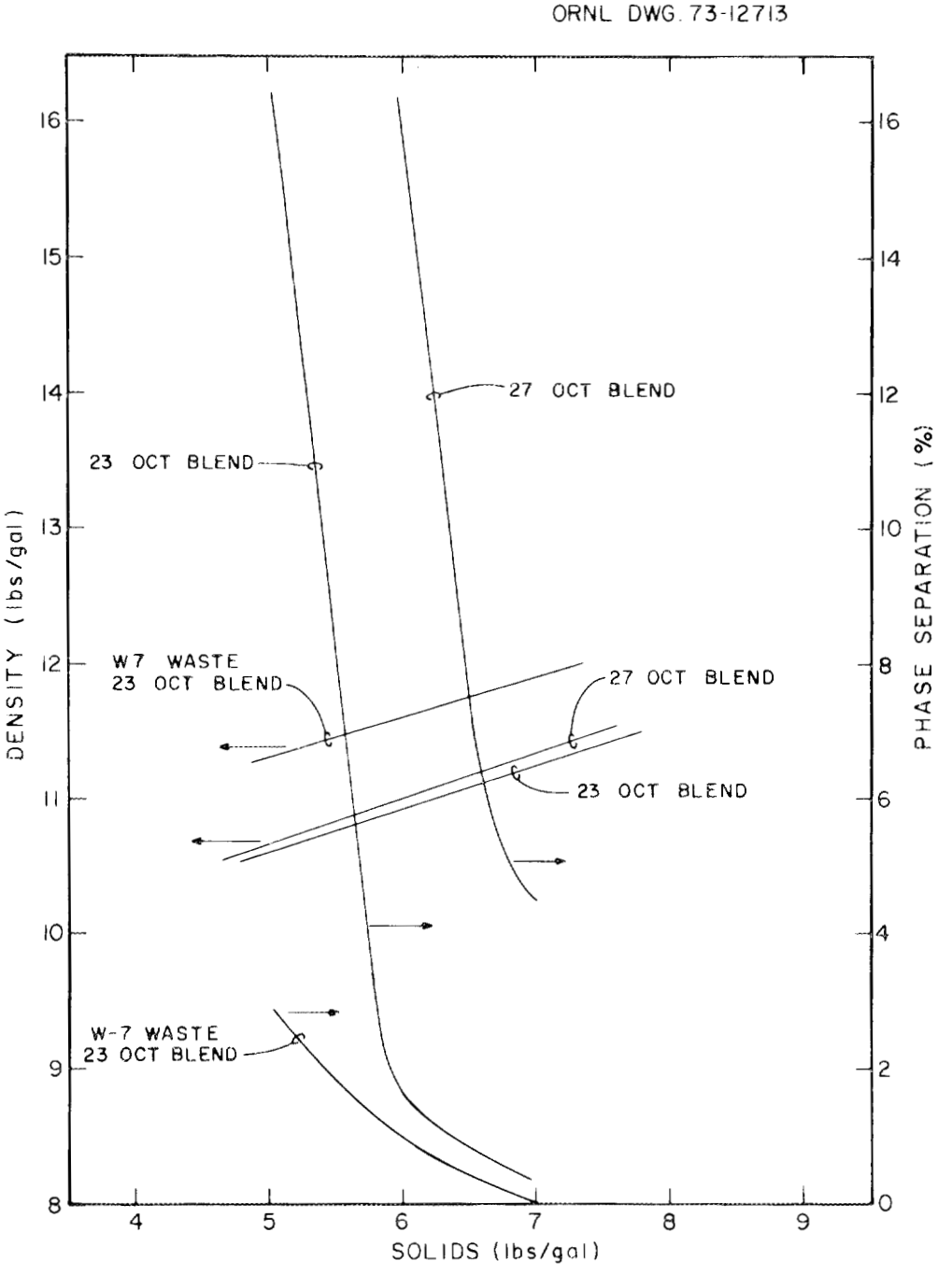

Fig. 20. Density and Phase Separation of Grout Prepared from W-7 Waste, Water, and Plant-Blended Solids for Use in Injection ILW-10.

A set of recommended weight ratios for the various combinations of waste and solids mixes and water was prepared. More solids were blended for this injection than for the first two injections, and each bin contained solids blended on at least two different days. In some instances these solids had rather different properties; thus, the recommended solids weight ratio for that particular bin could not be stated as a firm value.

6.2 Description of Injection

Injection ILW-10 was started at 10:14 on November 8. Water from the waste pit was mixed with solids from bin 4 and injected. Following 38 min of operation, the flow was switched to waste tank T-9.

At 11:40 the injection was halted and the packing of the injection pump was inspected. (This was a planned procedure and was not occasioned by any difficulty with the pump.) When the injection was restarted, the waste flow was switched to waste tank T-1 and the solids flow to bin 3.

At 1800 the quantity of solids remaining was judged to be sufficient for about 10 min of operation and the liquid flow was switched to water.

At 1810 the supply of solids was exhausted and the injection was stopped. Then the injection well was overflushed with 670 gal of water and valved shut. Finally, the facility was washed.

The wellhead pressure during Injection ILW-10 was about 300 to 400 psi lower than that measured during Injection ILW-9. This is about 600 psi higher than what is considered to be a normal injection pressure. Plots of the injection pressure and slurry flow rate are shown in Fig. 21. There is no clear relationship between these two parameters.

In general, this injection proceeded satisfactorily. Occasional difficulty was experienced with one of the Moyno waste pumps; that is, in three instances, the pump stopped and the injection was slowed or halted. In each case, however, the pump was restarted without delay. The cause of the pump stoppage is not known. An additional difficulty occurred because the readings of the mass-meter totalizer were not in good agreement with the known weights of solids in the storage bins. When bin 4 was emptied, for example, the mass totalizer indicated the contents weighed 14,500 lb less than was thought to be in the bin; when bin 3 was emptied, this discrepancy had increased to 23,000 lb. The final discrepancy amounted to

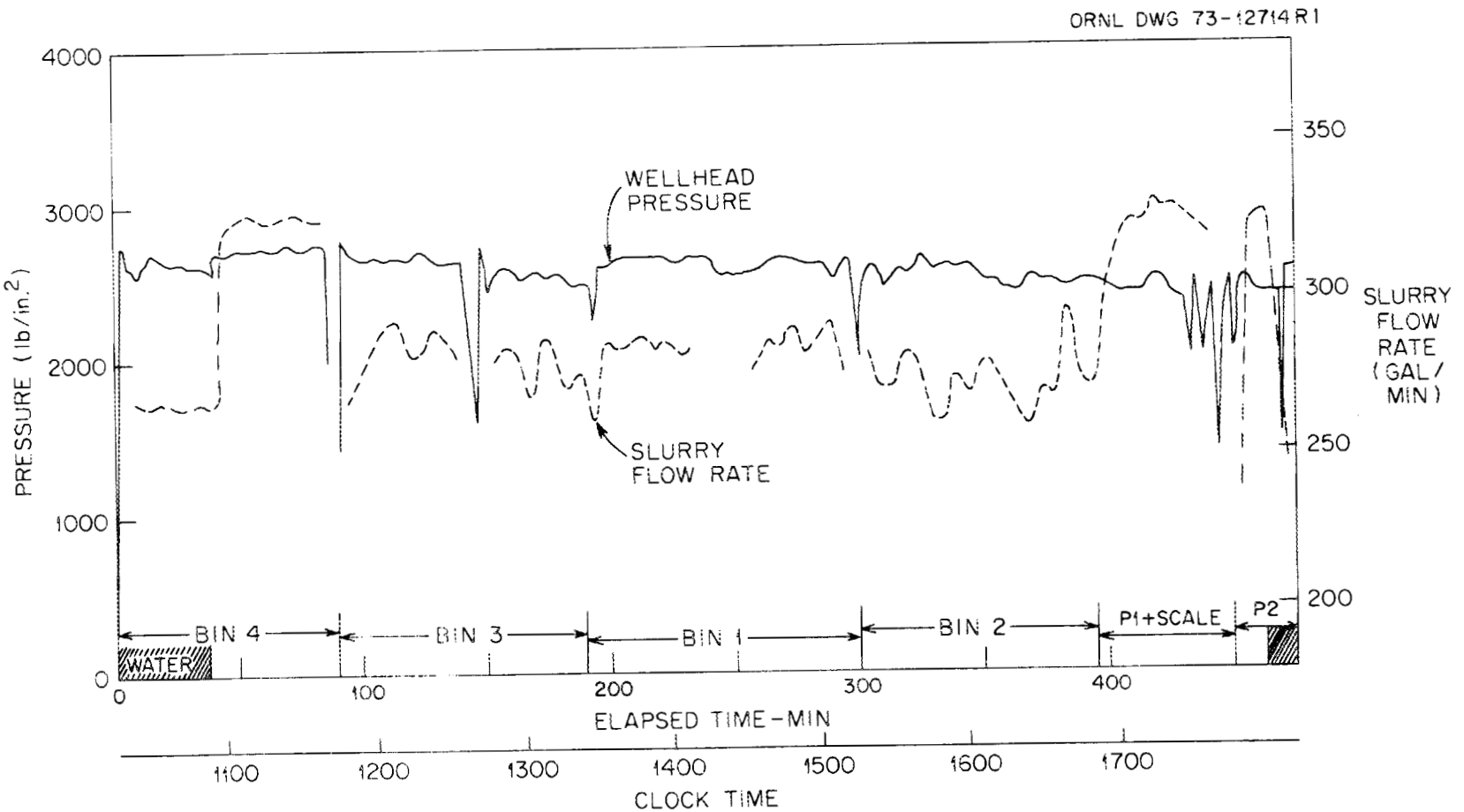

Fig. 21. Wellhead Pressure (Annulus) and Slurry Flow Rate During Injection ILW-10.

42,000 lb. Although such inconsistencies were bothersome, they had no effect on the progress of the injection. A mass-flowmeter error in this case would result only in the grout being somewhat thicker than planned. Visual observation of the grout in the sump tub indicated that the grout was quite fluid and in no danger of gelling; therefore, the mass flowmeter readings were assumed to be correct and were used to calculate the solids/waste weight ratio to be maintained throughout the run.

It was observed that the grout in the sump tub was much more fluid than grouts prepared for laboratory tests at the same solids/waste weight ratio. It is believed that this difference is caused by the greater amount of shear given the laboratory-blended samples during mixing. Because the laboratory samples are intended to simulate grouts that have been pumped down the injection well and into the fracture, some variation is to be expected. However, the magnitude of the variation was somewhat surprising. The window on the sump tub fogged badly during the early part of the run.

6.3 Data Analysis

Data collected during the injection are shown in Fig. 22 (the Densometer readings), Fig. 23 (the waste flow rate), and Fig. 24 (the solids flow rate). Values for the waste flow rate are taken from the flowmeter totalizer; values for the solids flow rate are taken from the mass-flowmeter totalizer. The flowmeter totalizer numbers are consistently about 4% higher than the waste tank level readings.

The mass-flowmeter readings indicate a total solids consumption of 635,500 lb, 41,880 lb less than the weight of solids available at the start of the injection. Comparison of totalizer readings with the weight of solids charged to individual bins indicates that the largest difference (23,000 lb) occurred when bin 2 was being emptied. An examination made of the bins on completion of the injection disclosed a thick layer of solids on the walls and bottom of bin 2. This layer was estimated to contain at least 10,000 lb of solids and perhaps all of the missing 23,000 lb. Bins 3 and 4 were virtually empty, whereas bin 1 contained appreciable solids, as did the blending tanks. It seems likely, therefore, that the quantity of solids remaining in the bins closely corresponds to the discrepancy (42,000 lb)

ORNL DWG 73-12715

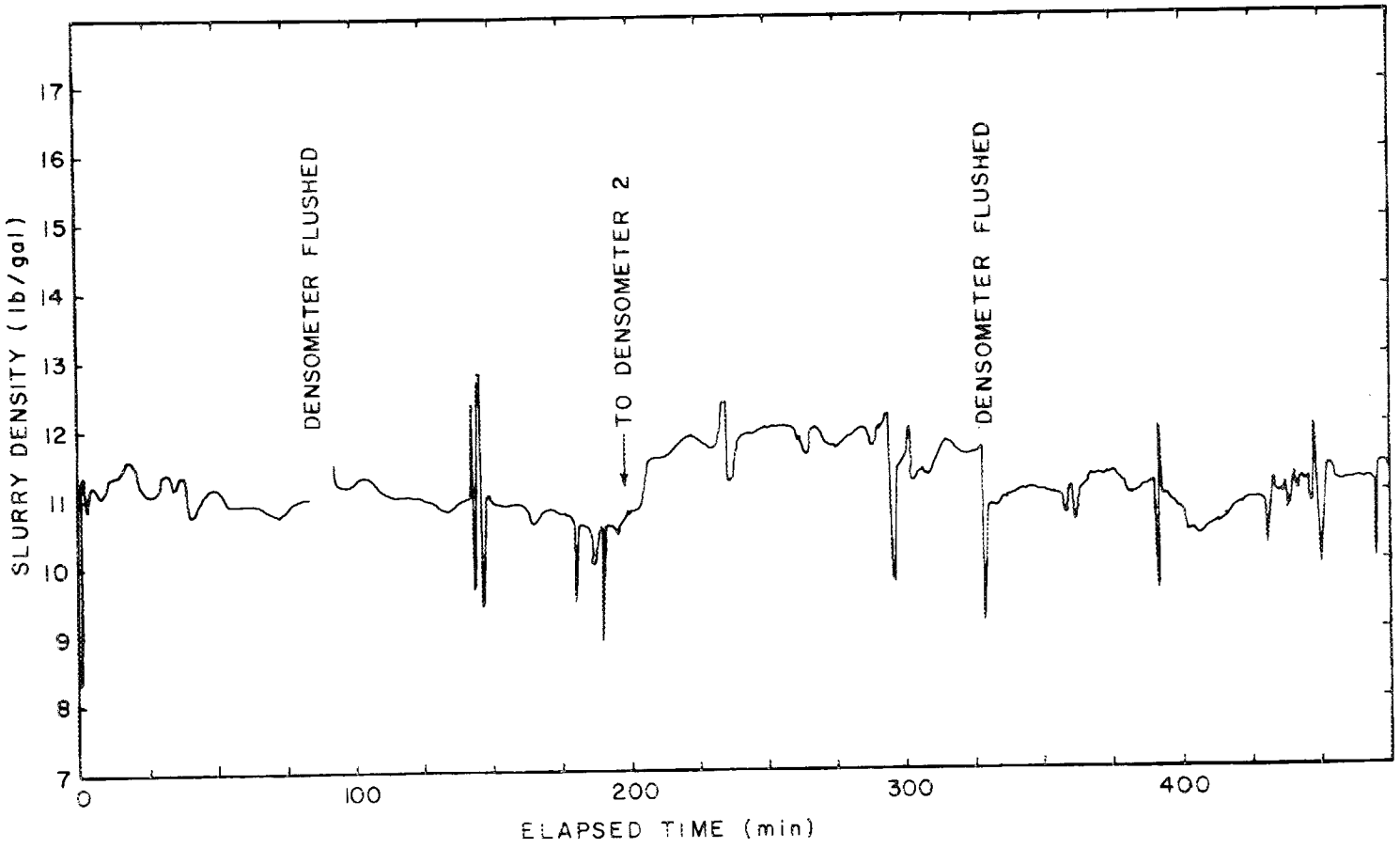

Fig. 22. Slurry Density During Injection ILW-10.

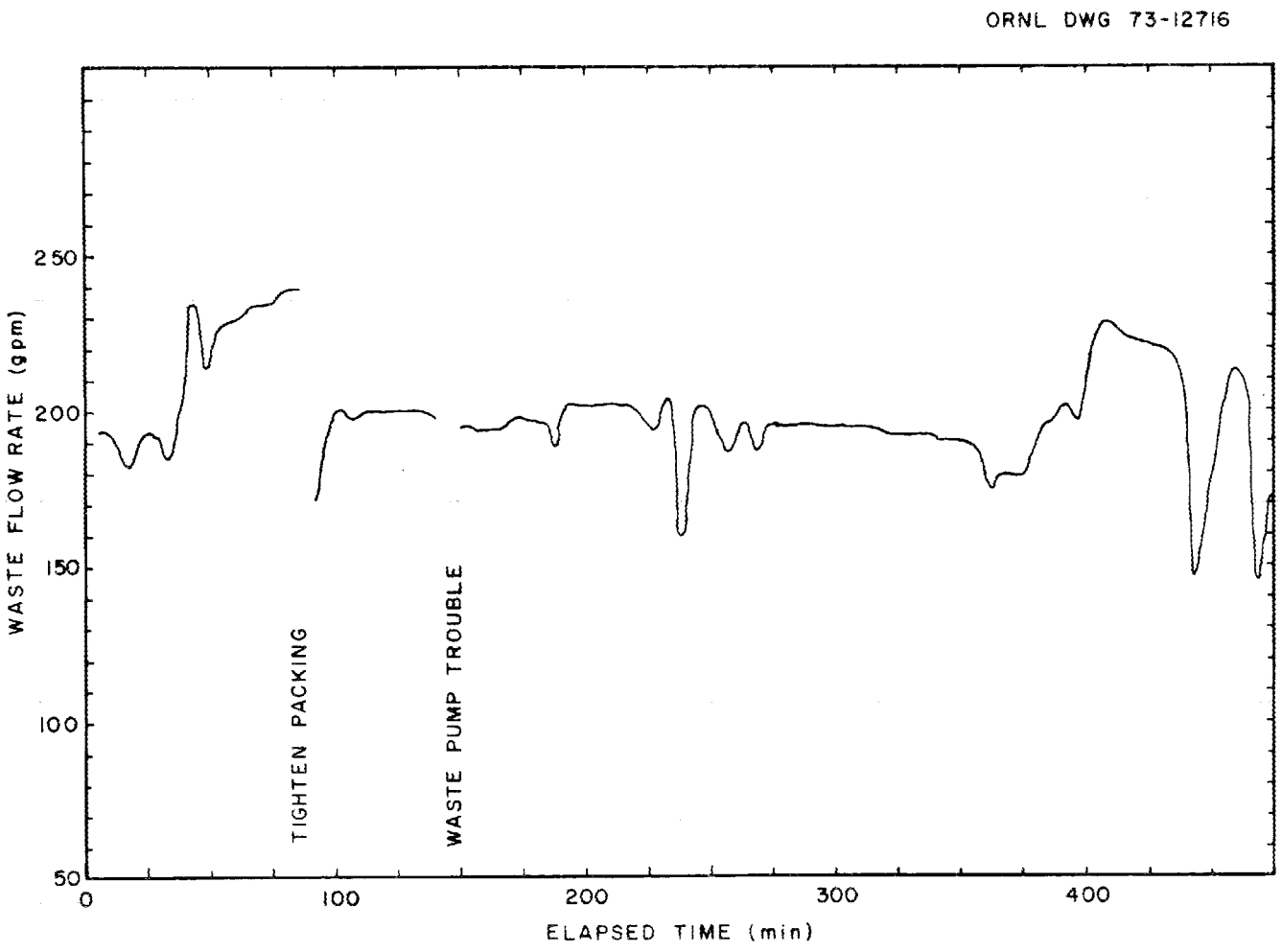

Fig. 23. Rate of Waste Flow from Flowmeter Totalizer During Injection ILW-10.

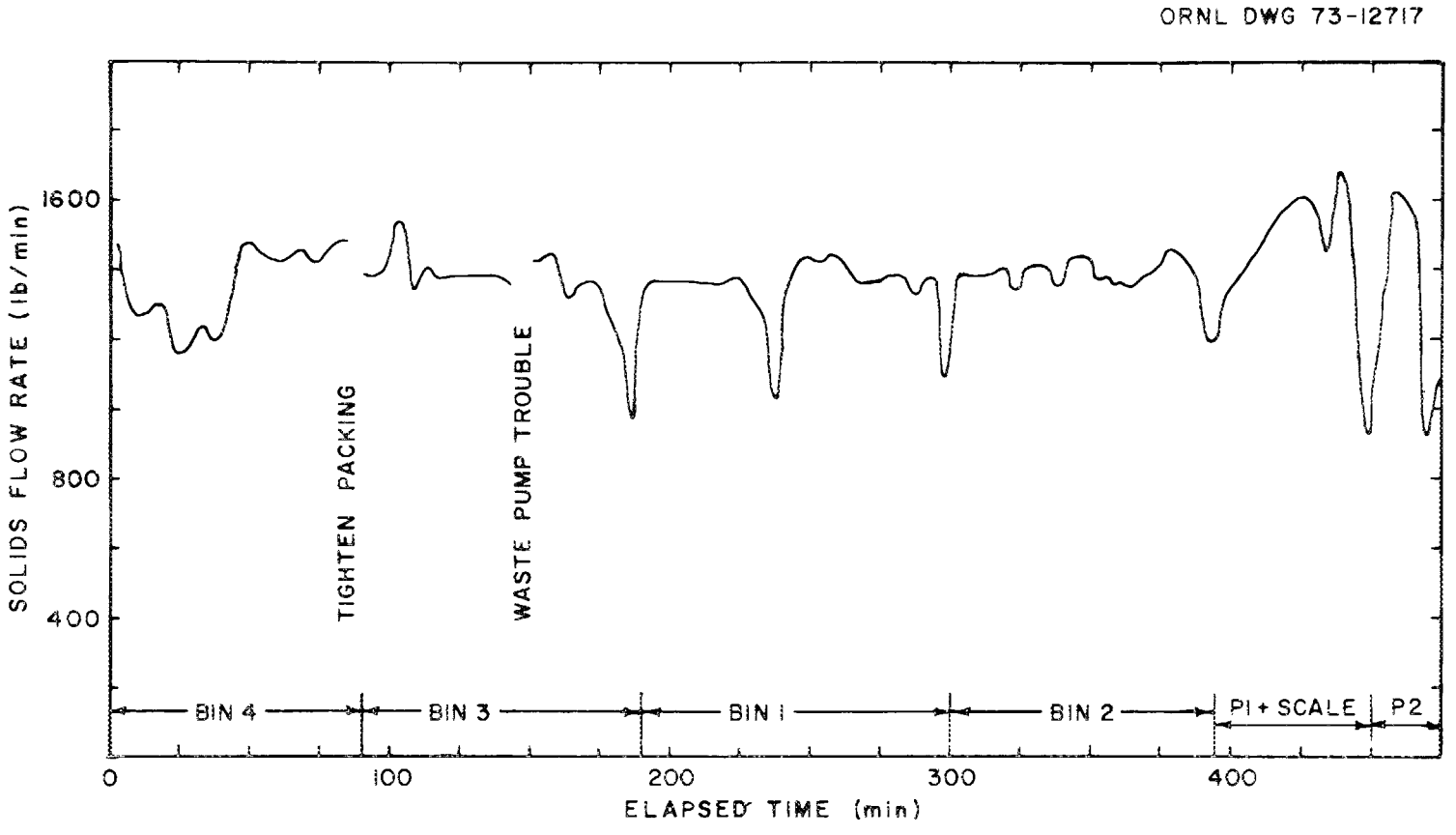

Fig. 24. Rate of Solids Flow from Mass-Flowmeter Totalizer During Injection ILW-10.

between the mass-flowmeter readings and the total solids charged to the bins. The mass-flowmeter readings are probably correct.

The Densometer readings are again inaccurate. During the first 3 hr of the run, the indicated density averaged 11.0 lb/gal. The equivalent mix ratio for this density is 5.3 lb/gal. For the same time interval, the mix ratio indicated by the mass flowmeter ranged from 6.5 to 7.0 lb/gal, a significant difference. For the time interval between 200 and 325 min, when Densometer No. 2 was in use, the Densometer readings were in reasonably good agreement with the mass-flowmeter readings. At 330 min, the Densometers were flushed and the indicated density dropped abruptly to a low (and erroneous) value. The Densometer readings proved to be a poor indication of mix ratios throughout this entire injection series.

The solids flow rate indicated by the mass flowmeter, divided by the liquid flow rate, gave the weight ratios shown in Fig. 25. Generally, the fluctuations in the ratio were within 1/2 lb/gal of the average; however, occasional fluctuations were greater.

The calculated injection parameters are summarized in Table 7. As shown, the average solids/waste ratios of the grout injected at various times were generally higher than the recommended ratios by about 1 lb/gal. The estimated values for anticipated phase separation were consequently quite low.

6.4 Radiation Doses Received

The radiation exposures received by Halliburton personnel during Injection ILW-10 (see Table 8) are considerably larger than those received in Injection ILW-9, primarily because of the two major maintenance jobs that were required (i.e., repacking the injection pump, and servicing the mass flowmeter). The exposure received during the injection itself was small and about the same as that received during each of the two previous injections.

Airborne radioactivity during the injection was monitored in the operating area and on top of the mixer cell. The detected radioactivity level in each location was higher than observed in previous injections. The average beta-gamma and alpha levels on top of the cell were 2.2×10^{-9} μCi/cc and 8.4×10^{-12} μCi/cc respectively. The corresponding levels in the operating area were 1.4×10^{-11} μCi/cc and 5.2×10^{-14} μCi/cc.

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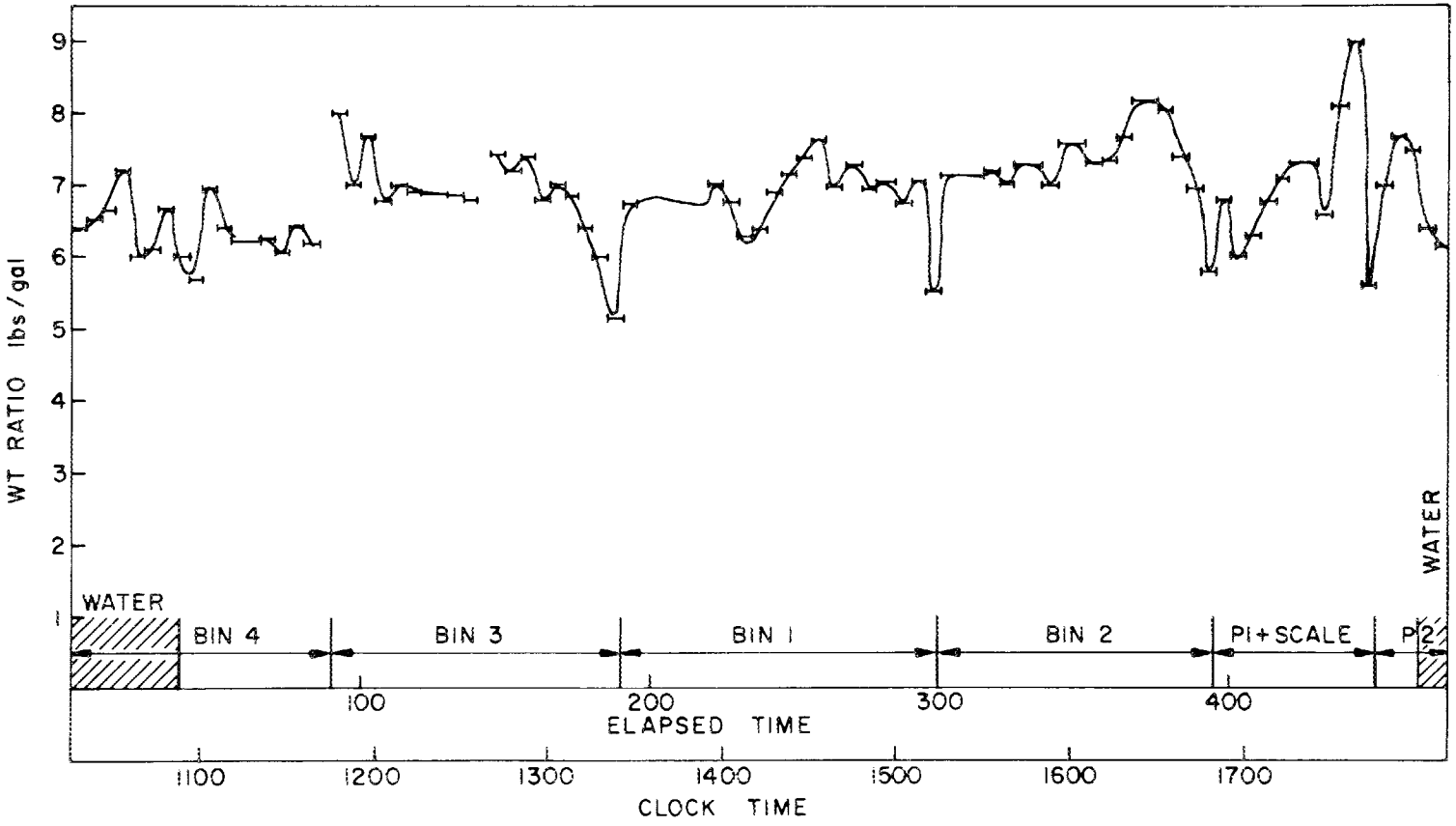

Fig. 25. Weight Ratios During Injection ILW-10.

Table 7. Calculated Parameters for Injection ILW-10

Clock Time		Elapsed Time			Waste Flow Rate	Solids Consumed		Weight Ratio	Estimate of Phase Separation	
From	To	(min)	Solution	Bin	(gal)	lb/min	lb	(lb/gal)	%	gal
1014	1052	38	Pit water	4	7,230	1,325	50,300	6.95	0.4	40
1052	1140	48	W-7 water	4	10,850	1,325	63,600	5.87	1.2	184
1144	1324	100	W-9 waste	3	18,850	1,310	131,000	6.95	0.1	27
1324	1512	108	W-9 waste	1	21,145	1,340	144,500	6.85	0	-
1512	1648	96	W-9 waste	2	17,985	1,360	130,600	7.26	0	-
1648	1745	57	W-9 waste	P-1	11,880	1,455	83,000	7.00	0.1	17
1745	1800	15	W-9 waste	P-2	3,050	1,510	22,600	7.41	0	-
1800	1810	10	Water	P-2	1,580	1,000	10,000	6.32	10.6	246
										514

Table 8. Radiation Exposures Received by Halliburton Personnel During Injection ILW-10

Job Description	Total Exposure (mR)	Maintenance Exposure		Injection Exposure	
		mR	% of Total	mR	% of Total
Cementer	160	128	80	32	20
Cementer	230	215	85	35	15
Mechanic	170	161	95	9	5
Mechanic	360	324	90	36	10
Mechanic	260	221	85	39	15
Instrument mechanic	400	380	95	20	5
Supervisor	160	88	55	72	45
Supervisor	400	360	90	40	10

7. INJECTION ILW-11

7.1 Preliminary Preparations

7.1.1 Facility Maintenance

The valve seats on the injection pump were replaced. A new Gadco dampener was installed on the high-pressure system to replace the one that failed prior to Injection ILW-10. A spinning disc viscosimeter was installed on the slurry tub so that the apparent viscosity of the grout in the tub could be determined. This viscosimeter was the same device that had been used in the laboratory to determine relative apparent viscosities of various grout mixes. It was installed inside a vertically mounted 3-in. pipe so that it could be extended down into the slurry or retracted back inside the pipe.

7.1.2 Waste Transfer

Waste solution was pumped to the site and distributed as follows:

T-1	14,880 gal
T-2	14,880 gal
T-3	24,760 gal
T-4	24,600 gal
T-9	12,950 gal

7.1.3 Blending of Solids

The solids left in bin 2 at the conclusion of Injection ILW-10 were scraped from the walls of the bin and collected in the bottom. The solids blended for Injection ILW-11 were then charged on top of these residual solids.

Four loads of solids were blended during the week of November 13. This exhausted the available Attapulgite 150 and, as a result, the blending operation was suspended until a new shipment could be received. The final two loads of solids were blended on November 27 and 28. A total of 690,000 lb of solids was blended and stored as indicated in Table 9.

The blending operation carried out on November 16 was performed with one P-tank out of service; thus, the number of transfers of solids made between tanks was one fewer for this batch than with other batches in this

Table 9. Distribution of Blended Solids for Injection ILW-11

Container	Blending Date	Weight (lb)	Total in Bin (lb)
4	November 13	111,000	-
4	November 14	39,490	150,490
3	November 14	81,000	-
3	November 15	78,400	159,400
1	November 15	40,660	-
1	November 16	104,700	145,360
2	Remaining from ILW-10	20,000[a]	-
2	November 27	118,800	138,800
P-2 tank	November 28	38,400	-
P-1 tank	November 28	38,000	-
Scale tank	November 28	39,800	-

[a]Estimated.

series. This batch of solids also had very low phase separation, but this may have been coincidental.

7.1.4 Formation Breakdown

The existing fracture at 832 ft was reopened by pumping 313 gal of water at a pressure of 2550 psi.

7.1.5 Compatibility of Waste and Solids Mix

The waste solution to be disposed of in Injection ILW-11 was contained in tanks W-9 and W-10. Analyses of these wastes are given in Table 1. The solids mix to be used was the same as that used in the three previous injections.

The solids required for the injection were blended and stored in the four bulk storage bins, the two blending tanks, and the scale tank. A sample was taken of the solids blended on each of the six blending days, and these samples were mixed with synthetic waste solutions at various solids/waste weight ratios. The density and phase separation of the resulting grouts were determined. The results indicated rather low phase separation for the blend prepared on November 16 and appreciably higher phase separation with the other blends. In general, the phase separations obtained with the blends for this injection were higher than those obtained with the blends for Injection ILW-10. As usual, the phase separations obtained when the various blends were mixed with water were much higher than those obtained when the blends were mixed with waste. At a mix ratio of 7 lb/gal, the observed phase separations were greater than 15% for all blends except that used on November 16 (1%) and on November 28 (4.4%).

A set of recommended mix ratios to be used with the solids blended on different days was prepared. For Injection ILW-11 each bulk storage bin contained solids blended on two different days. In some instances these solids produced mixes with rather different properties; therefore, the recommended solids weight ratio for that particular bin was not restricted to a single value.

7.2 Description of Injection

Just prior to the start of Injection ILW-11 the waste flowmeter jammed. Since the tank level measurements provided a good indication of the waste flow rate, the waste flowmeter was thought to be redundant; hence, the injection was made with this instrument inoperative. Also, prior to the start of the injection the viscosimeter became increasingly erratic, failed to maintain operating speed, and finally ceased operation. It was suspected that the motor had shorted out. Because immediate replacement of the motor was not feasible, this instrument was allowed to remain inoperative during the injection.

The injection was begun at 0937 on December 5. Water from the waste pit was mixed with solids fron bin 1 and injected. Even though the initial solids flow was low and erratic, normal flow was established within a few minutes. After 23 min of operation, the injection was stopped briefly to permit an adjustment to the injection pump to be made. At 1002 the injection was resumed.

At 11:20 the solids flow was switched to bin 2. The solids flow rate was low and erratic and at 11:30 the solids flow was switched to bin 3.

At 12:45 the injection was halted in order to permit the packing of the injection pump to be tightened. The injection was resumed at 12:49 with the liquid flow being switched to T-9 at this time.

At 13:03 the solids flow was switched back to bin 2, which had been aerated and vibrated while solids were withdrawn from bin 3. An adequate flow of solids was obtained this time.

At 15:40 the grout in the sump tub was observed to be quite thick and viscous. Simultaneously, the clutch on the injection pump jammed so that gears could not be shifted. (There was no known connection between these two events.) The injection was halted, the pump was manually shifted into a high gear, and the injection was resumed at 15:57. The tub full of thick grout was injected at an unusually high pressure (3500 psi); no further problems in this regard were experienced. However, considerable difficulty was encountered with the control of solids and liquid proportioning during the remainder of the injection. The injection pump was stuck in high gear and could not be run slowly. An obstruction in the jet feed

hopper reduced the maximum flow of solids that could be maintained; consequently, the desired solids/liquid ratio could not be achieved. At 17:05 the liquid flow was switched to water. When at 17:09 the solids flow had virtually ceased, the injection was stopped. The injection well was overflushed with 420 gal of water and valved shut. Finally, the facility was washed.

The average wellhead pressure during Injection ILW-11 was slightly lower that that measured during Injection ILW-10. However, the average injection rate was considerably higher during Injection ILW-11 so that the two pressures cannot be compared directly. The high injection pressure (3500 psi) that was observed on restarting the injection following the difficulties with the injection pump clutch (when the thick grout in the slurry tub was injected) suggests that the viscosity of the grout has at least as much effect on the injection pressure as does the injection rate. The final hour of the injection provided another indication of the effect of grout viscosity on injection pressure. During this period the injection rate was high, whereas both the solids content and viscosity of the grout were low. The wellhead pressure was some 300 psi lower than it was prior to the shutdown. A plot of the injection pressure (measured at the annulus) and the grout injection rate is shown in Fig. 26.

This injection was marked throughout by difficulties in initiating and maintaining an adequate flow of solids to the mixer. It is suspected that the stored solids had become agglomerated as the result of dampness and, consequently, would not flow smoothly. There is no particular known reason why these solids should contain more moisture than those in other injections except that they had been stored somewhat longer than usual. From 20,000 to 40,000 lb of solids remained after the previous injection, and four of the six batches of solids used in this injection were blended three weeks prior to the injection, about two weeks earlier than was the case for previous injections.

As in Injection ILW-10, the mass-flowmeter readings were not in good agreement with the known weights of solids in the storage bins. The differences between the mass-flowmeter totalizer readings and the weights of solids charged to the various bins were as follows: Bin 1 - 12,000 lb, Bin 2 - 29,000 lb, Bin 3 - 39,000 lb, Bin 4 - 19,000 lb, P-tanks (Bin 1, refilled)

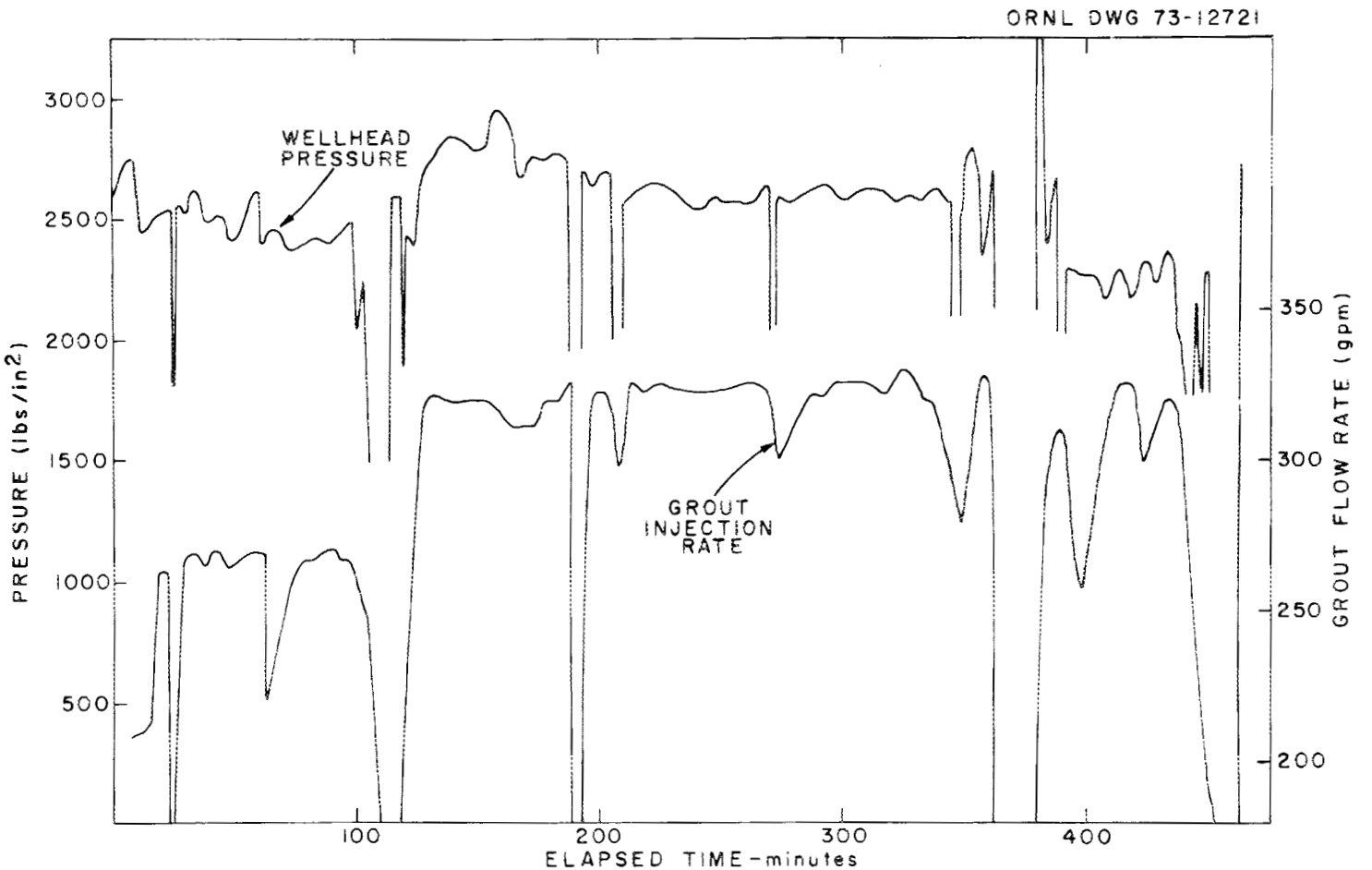

Fig. 26. Wellhead Pressure and Grout Injection Rate During Injection ILW-11.

- 25,000 lb. The bins were inspected after the injection. The P tanks and Bin 1 were found to be empty, or nearly so. Bin 2 contained an estimated 41,000 lb of solids, while Bins 3 and 4 each contained an estimated 27,000 lb. The total mass of these residues is in reasonable agreement with the mass-meter discrepancies, but the distribution between various bins is not as expected.

Despite these troubles the injection was completed without serious difficulty. The control of the mix ratio was less precise than in previous injections, and about 10,000 gal of waste could not be injected because of the failure of solids flow. However, neither of these difficulties was considered to be major.

7.3 Data Analysis

Data collected during the injection are shown in Fig. 27 (the Densometer readings), Fig. 28 (the indicated waste tank levels), and Fig. 29 (the solids flow rate). Values for the solids flow rate are taken from the mass-flowmeter totalizer.

The mass-flowmeter readings were not in good agreement with the weight of solids charged to the storage bins. The sum of the total weight injected, as indicated by the mass-flowmeter totalizer, and the estimated weight of solids left in the bins at the end of the injection is close to the total weight of solids on hand at the start of the injection; on the other hand, the mass-flowmeter readings indicated that a large amount of solids should remain in bin 1 (no solids were found) and comparatively few solids should remain in bin 2 (an estimated 41,000 lb was found). Similar discrepancies were noted for bins 3 and 4. Several factors could be involved in these differences:

(1) The mass-flowmeter readings could be erroneous.

(2) Solids charged to a particular bin could have been forced through the interconnecting vent piping to a different bin.

(3) Solids noted as originating from a particular bin could have come from several bins. Such multiple feeding of the mass flowmeter is known to have occurred on several occasions, usually toward the end of an injection when all bins were

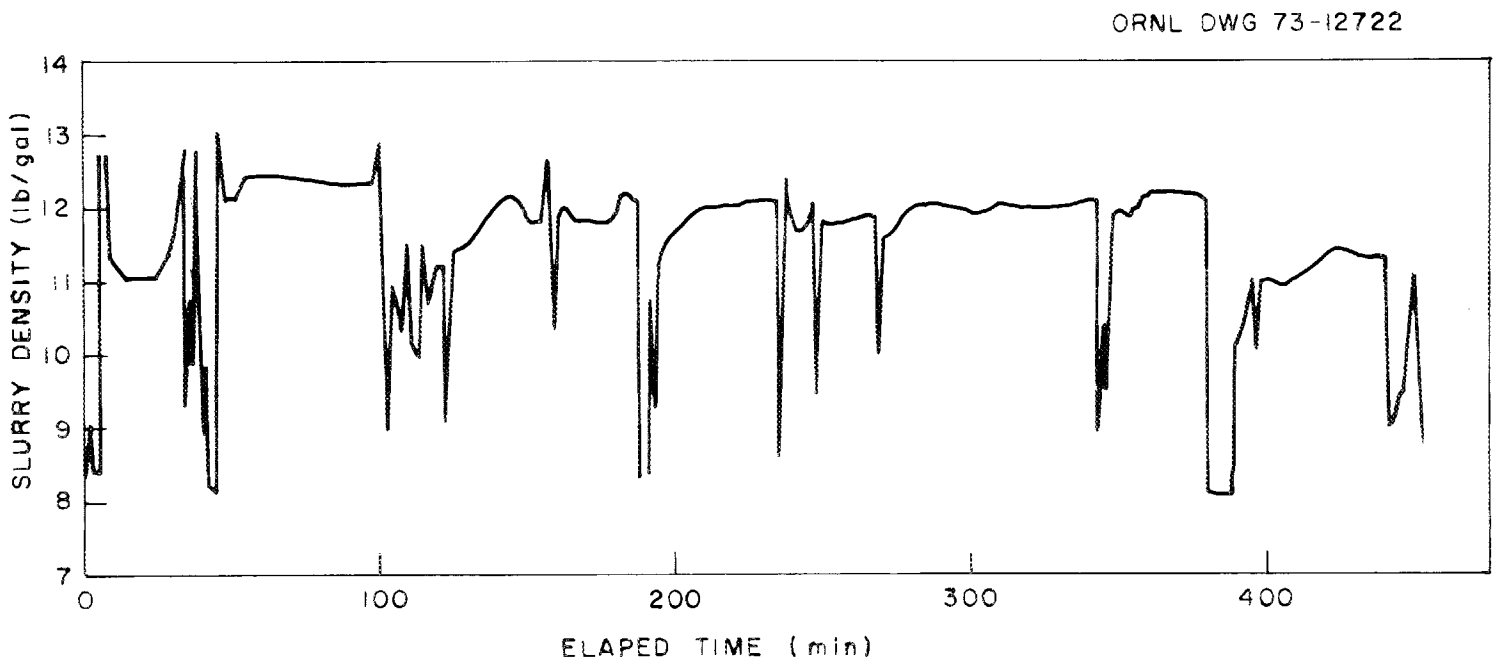

Fig. 27. Slurry Density During Injection ILW-11.

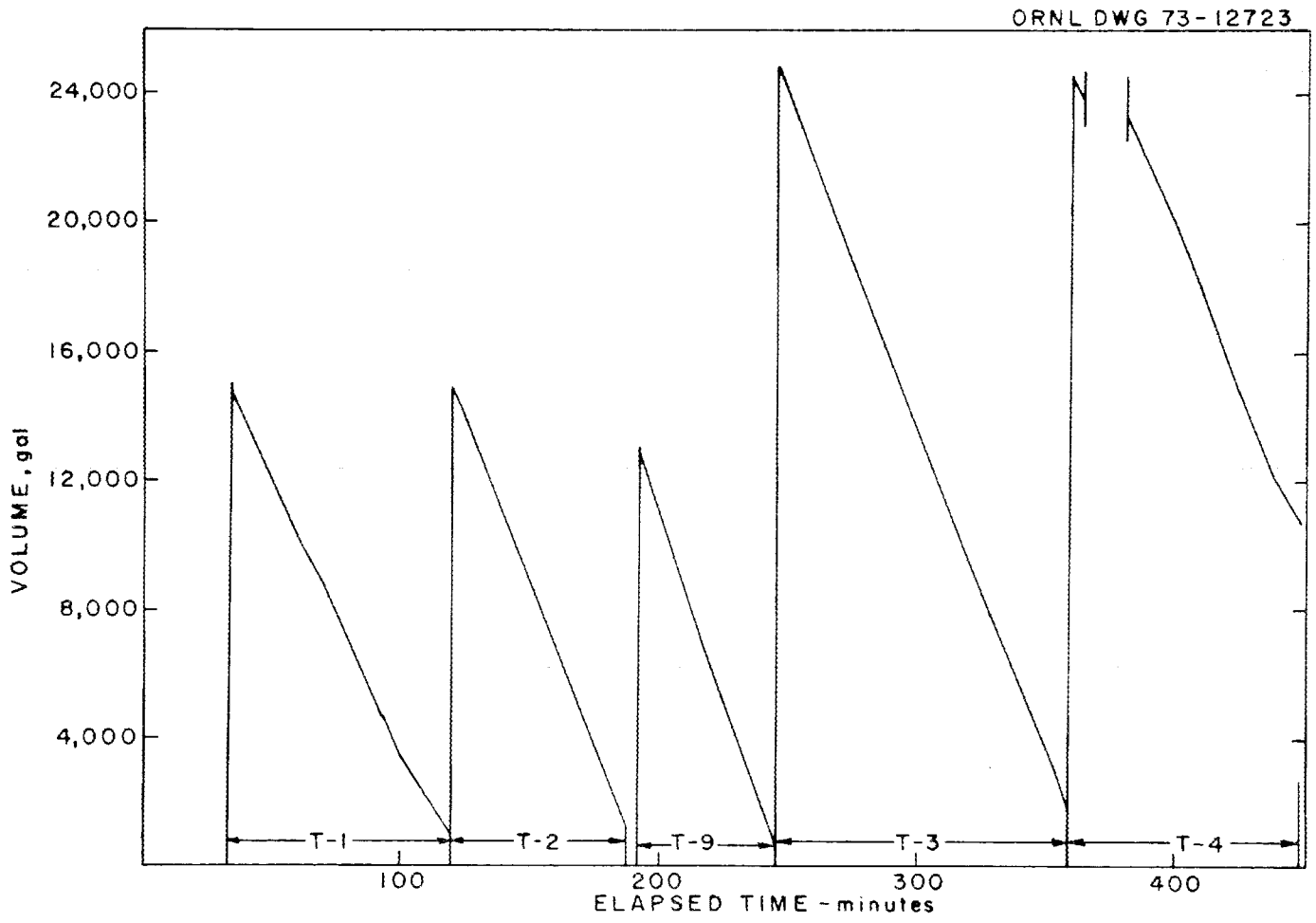

Fig. 28. Waste Tank Levels During Injection ILW-11.

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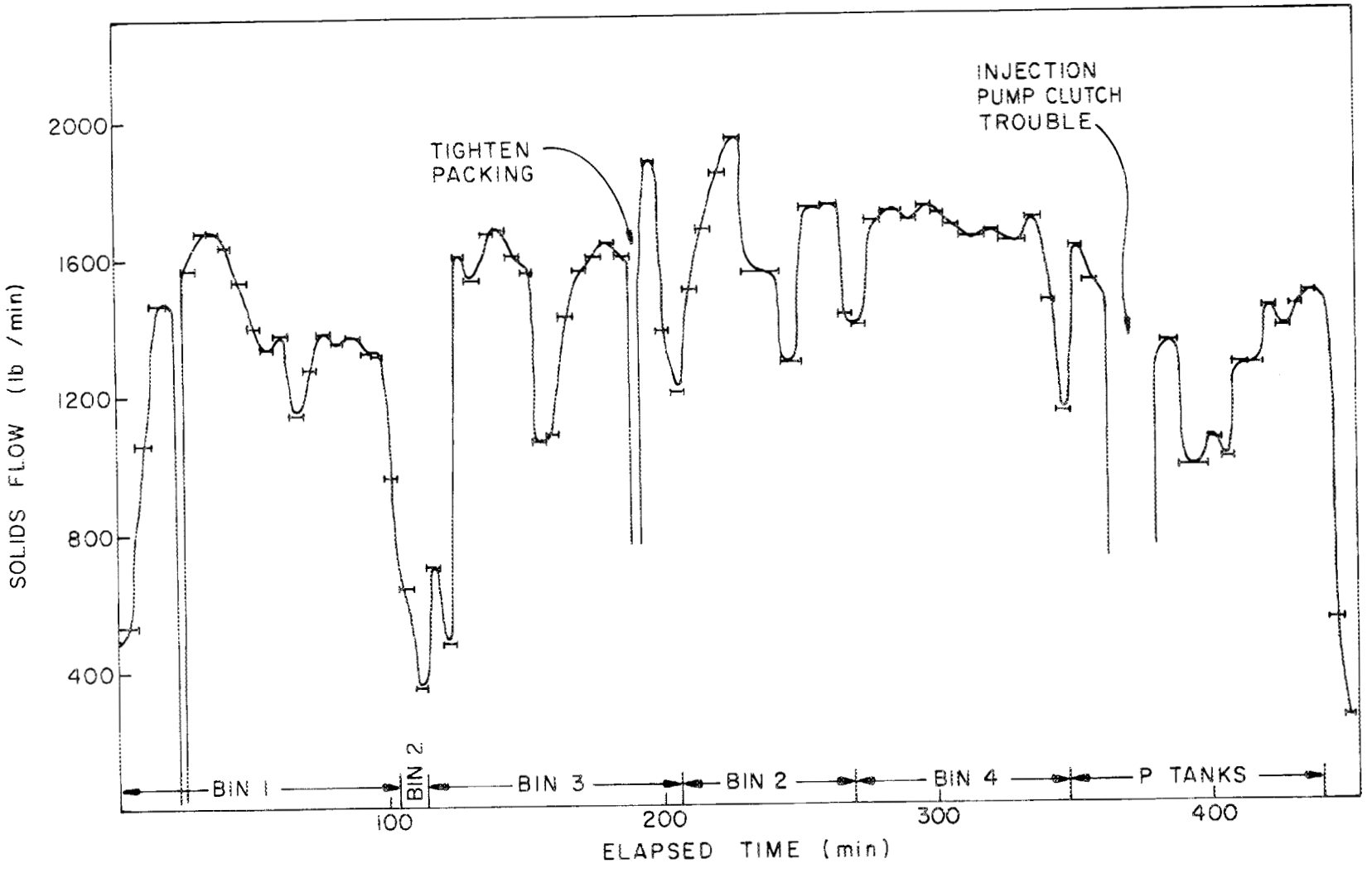

Fig. 29. Solids Flow Rate During Injection ILW-11.

nearly empty. It is not believed that any large quantity of solids was withdrawn from the bins during these occasions.

(4) The dust collector that was located on bin 2, and periodically discharged collected solids into bin 2, could have been responsible for the transfer of some solids from the other bins into this bin. Most probably, all of these factors were involved to some extent.

The Densometer readings gave a much better indication of slurry density during this injection than in previous injections. The indicated density trace was much smoother than heretofore, and a mix ratio calculated from this trace checked with the mix ratio calculated from the mass-flowmeter readings to within an average of 0.7 lb/gal.

Since the waste flowmeter was inoperative during the injection, the waste tank level readings (Fig. 28) were used to determine the waste flow rate (Fig. 30). The curve of these calculated flow rates looks somewhat peculiar since it contains several abrupt changes that do not appear in the curve of the grout injection rate (Fig. 26). Such changes arise because an insufficient precision in the waste tank level readings can result in large errors when two readings are subtracted.

The solids flow rate indicated by the mass flowmeter, divided by the liquid flow rate, gives the mix ratio shown in Fig. 31. The fluctuations in this mix ratio are much greater than those obtained for previous injections, primarily because of the difficulties in maintaining a smooth flow of solids during ILW-11. The periods when the mix ratio was low are coincident, for the most part, with periods switched between bins and the flow of solids was spasmodic.

The calculated injection parameters are summarized in Table 10.

7.4 Radiation Doses Received

The radiation exposures received by Halliburton personnel are listed in Table 11. The total exposures are about the same as those received during Injection ILW-10. A large fraction of the exposures was accumulated during maintenance operations on the injection pump because the special tool for removing the valve seats could not be located and the job had to

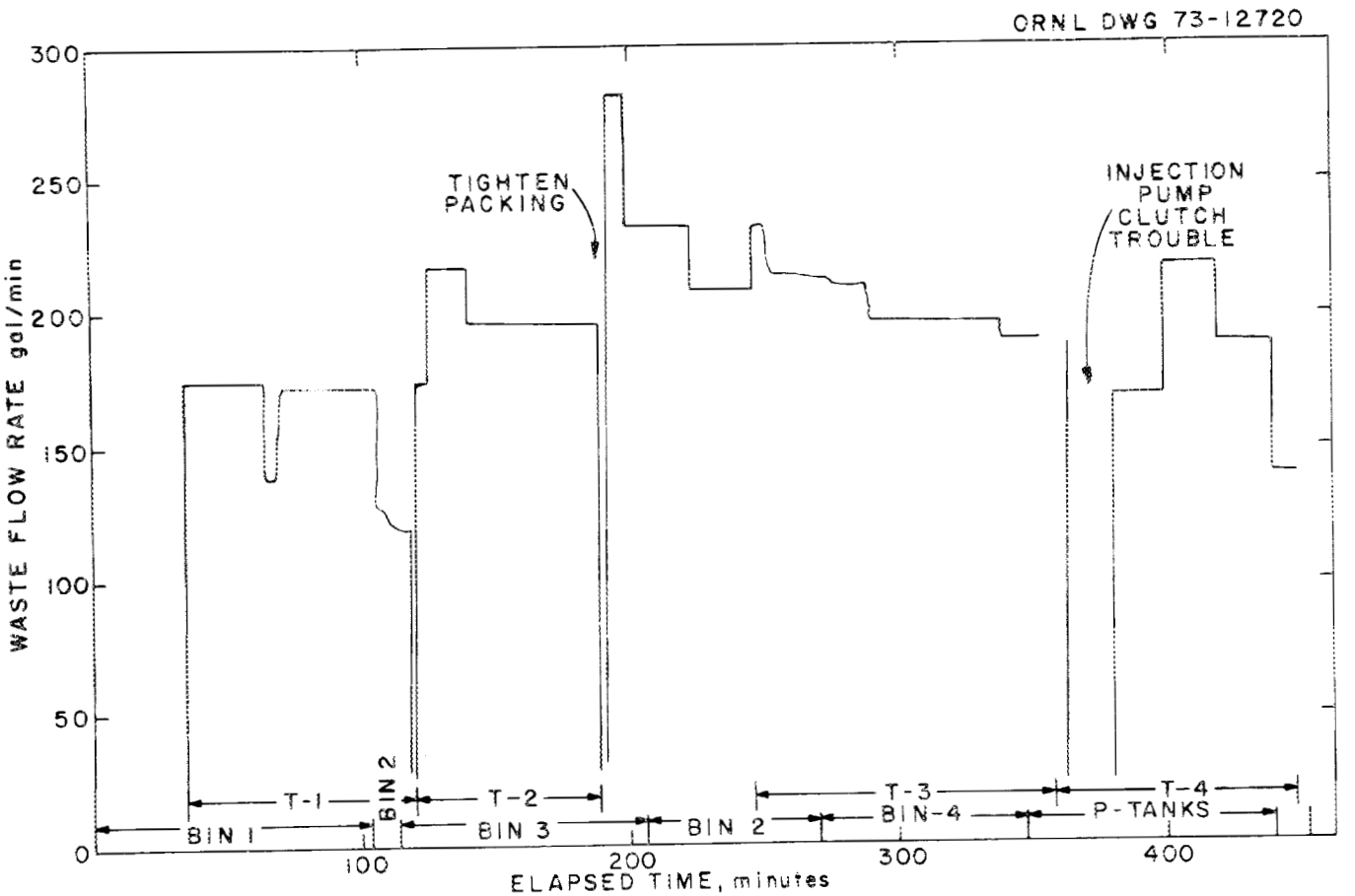

Fig. 30. Rate of Waste Flow, as Determined from Waste Tank Level Measurements, During Injection ILW-11.

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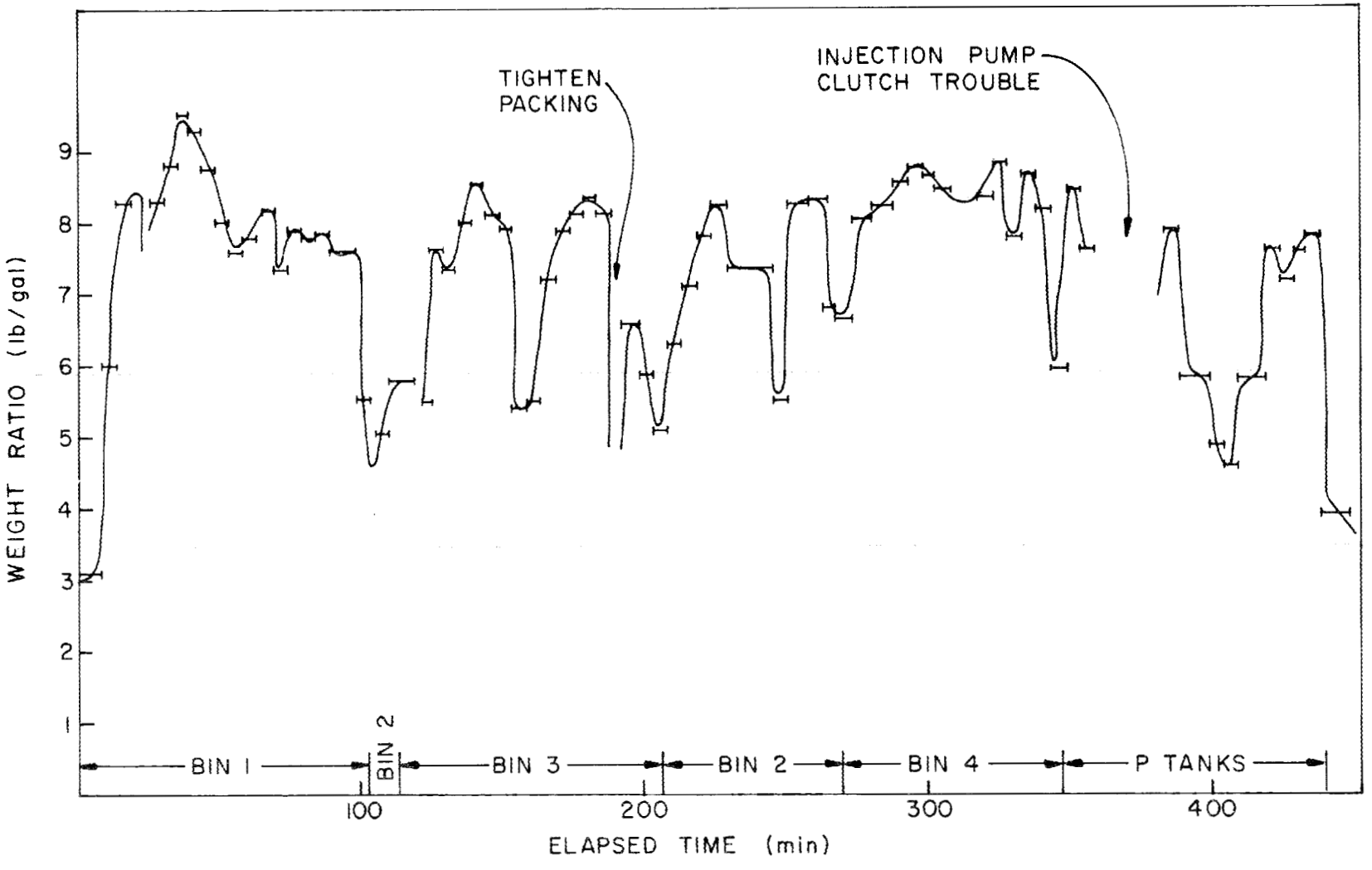

Fig. 31. Mix Ratio for Injection ILW-11.

Table 10. Calculated Parameters for Injection ILW-11

Clock Time		Elapsed Time			Waste Flow	Solids Consumed		Weight Ratio Based On:		Estimated Phase Separation	
From	To	(min)	Solution	Container	(gal)	lb/min	lb	Densometer	Mass Flowmeter	%	gal
0937	1000	23	Pit water	1	4,100	1,100	25,300	4.5	6.2	20	1,150
1002	1011	9	Pit water	1	1,720	1,620	14,600	6.9	8.5	8	189
1011	1120	69	Waste	1	11,796	1,360	93,900	8.7	7.95	0	0
1120	1130	10	Waste	2	1,287	550	5,500	3.0	4.3	15	260
1130	1245	75	Waste	3	14,371	1,360	101,800	7.0	7.1	0.7	160
1249	1303	14	Waste	3	3,320	1,350	18,900	4.8	5.9	2.2	90
1303	1408	65	Waste	2	14,403	1,610	104,400	7.6	7.25	0.2	42
1408	1524	76	Waste	4	15,184	1,650	125,300	7.2	8.25	0.3	72
1524	1540	16	Waste	P-tank	2,701	1,460	23,300	8.8	8.6	0.1	5
1557	1705	68	Waste	P-tank	12,700	1,070	72,700	4.5	5.7	1.5	290
1705	1709	4	Water	Dregs	525	250	1,000	-	2.0	30	210
										Total	2,468

Table 11. Radiation Exposures Received by Halliburton Personnel During Injection ILW-11

Job Description	Total Exposure (mR)	Maintenance Exposure		Injection Exposure	
		mR	% of Total	mR	% of Total
Cementer	190	175	92	15	8
Cementer	330	297	90	33	10
Mechanic	270	238	88	32	12
Mechanic	480	461	96	19	4
Mechanic	200	178	89	22	11
Instrument mechanic	130	117	90	13	10
Supervisor	250	235	94	15	6
Supervisor	160	150	94	10	6

be done with improvised equipment. This necessarily required a longer period of time and resulted in additional radiation exposure. The exposure received during the injection itself was small, even lower than in previous injections.

Airborne radioactivity during the injection was monitored in the operating area and on top of the mixer cell. In the operating area, the emission levels were approximately the same as were detected during the preceding injection (average beta-gamma level of 1.1×10^{-11} μCi/cc, and average alpha concentration of 3.7×10^{-14} μCi/cc). On top of the mixer cell the average beta-gamma and alpha concentrations were 2.7×10^{-9} μCi/cc and 5.5×10^{-11} μCi/cc respectively; these levels are appreciably higher than those observed in ILW-10.

8. POST-INJECTION EVALUATIONS

8.1 Seismic Measurements

No meaningful seismic signals were obtained from any of the injections in this series. This absence of signals was disappointing.

8.2 Logging

The observation wells were logged after each injection; the results are given in Table 12. A diagram of some of these results (i.e., those on a north-south section through the injection well) is shown in Fig. 32. A considerably greater vertical movement of the grout sheet occurred in Injections ILW-10 and ILW-11 than had been observed in most of the previous injections. The largest vertical movement was observed in wells N100 and NW100, cores from which have shown that the bedding of the shale is less regular than in other wells in the area. Probably, this abnormality in the shale formation has affected the movement of the grout sheets in this direction.

8.3 Composite Waste Analysis

A composite sample was taken from the waste solution that was pumped to the shale fracturing site prior to each injection. Radiochemical analyses of the samples are given in Table 13. The most surprising aspect of the data is the rapid rise in concentration of ^{244}Cm from each injection to the next.

8.4 Bleedback

Any unbound water that may exist in contact with the grout sheets is routinely bled back from the injection well a short time after the end of an injection. For example, bleedback after Injection ILW-7 was started 40 days after completion. The initial rate of bleedback was in excess of 100 gal/hr, but this rate decreased exponentially and was only 2-1/2 gal/hr after 4000 gal had been recovered. A total of about 10,000 gal was ultimately collected. The plans for this injection series called for four injections to be made in prompt succession, and neither a 40-day waiting period nor a long bleedback period was feasible for any of them except the last. The bleedback procedure was therefore modified; the waiting period was reduced to 10 days, and the recovery between injections of less than the total volume of unbound water was accepted. (It was thought probable that any unbound water not recovered after a particular injection could be recovered after a succeeding injection.)

Table 12. Elevations (in ft) of Grout Sheets in Observation Wells

(all elevations are related to mean sea level)

Well	Injection			
	ILW-8	ILW-9	ILW-10	ILW-11
Injection well	-40	-40	-40	-40
W300	a	-41 to -45	-9 to -19	a
NW100	-18	a	+45 to +45	+28 to +30
N100	a	a	+38 to +39	+24 to +26; +29, +34, +38
N150	a	-32 to -34	+18; +19; +21; +24	+11 to +12; +13 to +15
NE125	a	a	+14 to +16; +23; +34	-5 to -7; +2 to +4; +7 to +12
E320	a	a	a	a
S100	-46 to -52	-52 to -54	a	-22
S220	a	a	a	

[a]No grout sheet found.

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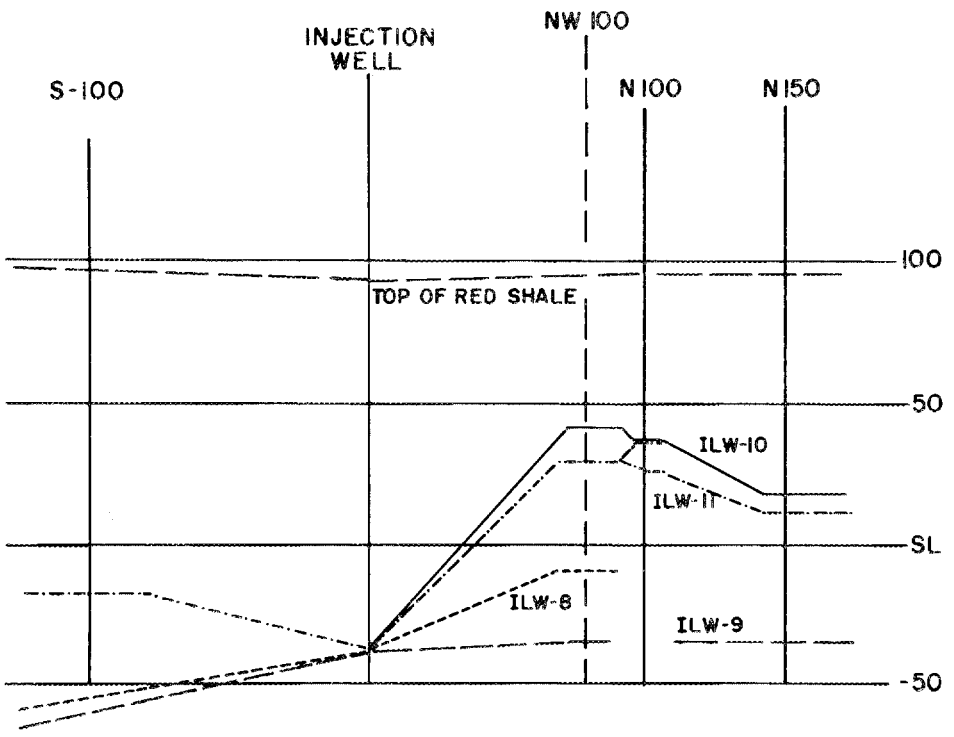

Fig. 32. Vertical Orientation of Grout Sheets in North-South Section.

Table 13. Radiochemical Analyses of Waste Solutions (in Ci/gal)

	ILW-8	ILW-9	ILW-10	ILW-11
^{90}Sr	6.23×10^{-4}	3.38×10^{-3}	1.57×10^{-2}	1.45×10^{-2}
^{137}Cs	0.384	0.342	0.222	0.31
^{106}Ru	0.0347	0.0055	0.007	0.005
^{244}Cm	2.55×10^{-6}	8.25×10^{-5}	3.4×10^{-4}	1.97×10^{-3}
Pu	1.8×10^{-6}	a	a	a

[a]None present.

A summary of the bleedback data is given in Table 14. The rate of bleedback from Injection ILW-8 was quite low; however, the rate for subsequent injections was progressively higher, so much higher that no significant fraction of the total volume could be recovered during the period between injections without disruption of the preparations for the subsequent injection. Therefore, after Injection ILW-10, the bleedback procedure was modified to determine whether the rate of bleedback varied with well shut-in time. The bleedback rate was determined 11 days after completion of the injection and the well was then closed; 10 days later, the well was reopened and the bleedback rate was redetermined. There was a significant difference between the two bleedback rates. The bleedback rate was determined in the same manner at 9, 24, 45, and 110 days following Injection ILW-11 and was observed to decrease sevenfold over this time interval. At the conclusion of these determinations, the well was left open and the bleedback water was collected. After 128 days the bleedback volume totalled 11,600 gal, and the rate had decreased to less than 0.6 gal/hr. The accumulated water was pumped back to the tank farm in Bethel Valley and the well was valved shut. Fig. 33 shows the bleedback volume.

The data show that the initial rate of bleedback (and probably the total bleedback volume) decreases drastically with an increase in shut-in time. There is no known reason for the difference between the initial bleedback rates after different injections; apparently, no correlation exists between initial bleedback rates and the wellhead pressure prior to starting bleedback. For a given injection, however, such a relationship does appear to exist. For instance, the wellhead pressure after Injection

Table 14. Bleedback Data

Injection	Well Opened	Days After Injection	Wellhead Pressure (psig)	Initial Flow Rate (gph)	Final Flow Rate (gph)	Volume Recovered (gal)
ILW-8	October 9	10	245	11	6.2	1,160
ILW-9	October 27	10	310	120	72	3,380
ILW-10	November 20	11	205	475	390	670
	November 30	21	150	258	222	585
ILW-11	December 14	9	245	306	-	570
	December 29	24	170	162	-	415
	January 19	45	140	96	-	300
	April 4	110	83	45	0.57	11,600 (after 128 days)

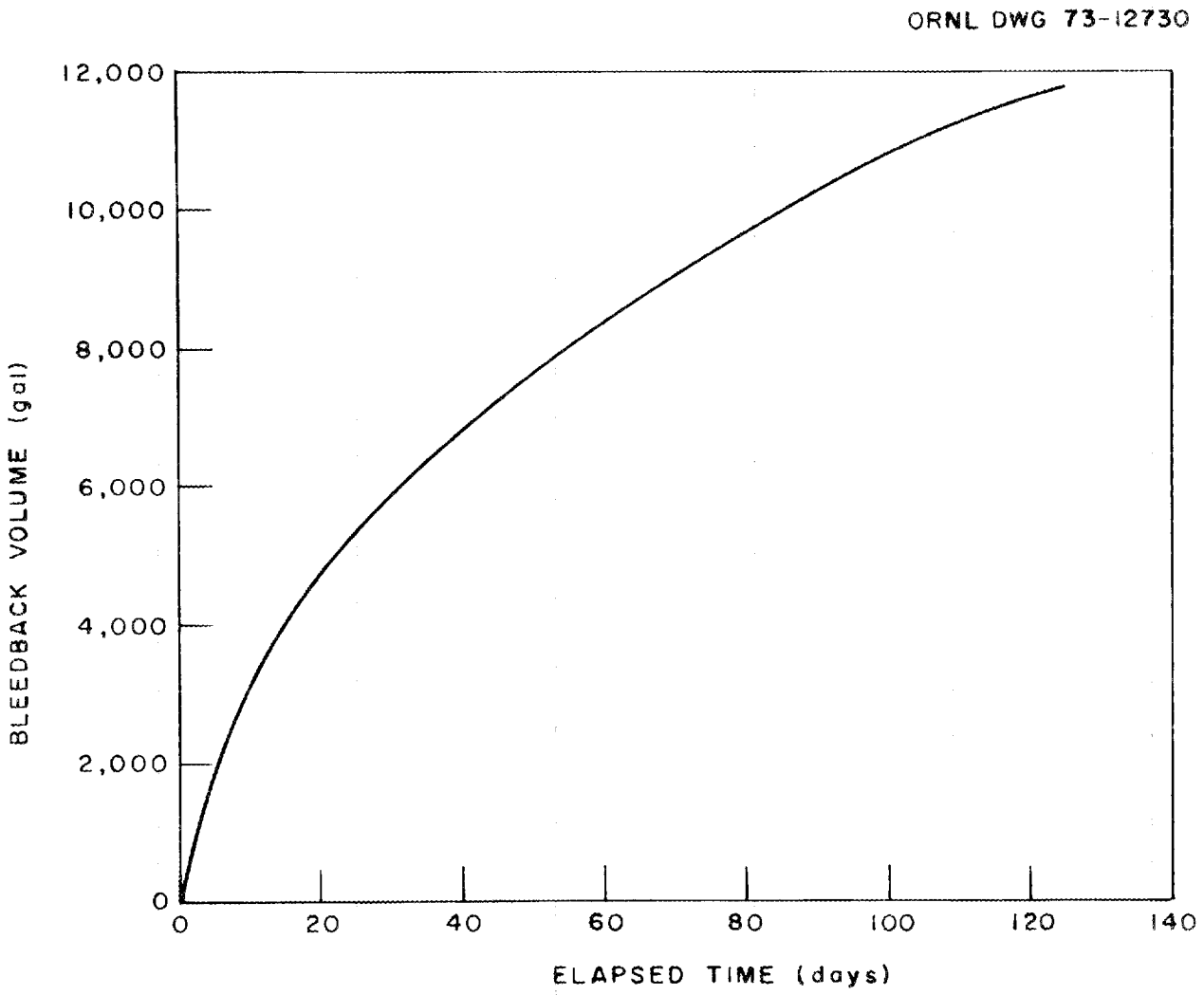

Fig. 33. Bleedback Volume from Injection Well After Completion of Injection Series.

ILW-11 fell from 245 to 83 psi while the initial bleedback rate was decreasing from 306 to 45 gph. This decline in wellhead pressure could be accounted for by a relatively small rise in grout compressive strength over the same interval. It seems likely that water which is bled back is not "free" water but is held in the pores of the set grout as long as the well is closed. When the well is opened, the weight of the overlying rock compresses the grout sheets and squeezes the unbound water out of the grout pores. A grout with a high compressive strength (because of high cement content or a long set time) would have less water squeezed out and a lower bleedback rate. This suggests that the compressive strength of the grout may be a more pertinent factor in mix evaluations than has been assumed heretofore.

Some analyses of the bleedback solutions are given in Table 15. A comparison of the values in this table with the values in Table 14 shows that the grout successfully retains most of the radionuclides. The concentration of alpha emitters was low and did not vary appreciably between injections, even though the concentration in the waste solution varied by almost three orders of magnitude. It seems likely that the alpha emitters are very strongly retained by the grout and that only trace levels are picked up by the unbound water. The ^{137}Cs concentration in the bleedback solutions is approximately 1% of that in the corresponding waste solutions. The ^{90}Sr concentration in the bleedback solutions is essentially constant, even though the concentration of this isotope in the waste solution varied by a factor of 20. For the last two injections, the ^{90}Sr concentration in the bleedback was 4% of the concentration in the waste solution.

8.5 Noise Levels

The noise levels were measured at various locations at the shale fracturing site during blending (September 20) and during an injection (October 17). The results are given in Table 16.

Table 15. Analyses of Bleedback Solutions

	Injection			
	ILW-8 (Ci/gal)	ILW-9 (Ci/gal)	ILW-10 (Ci/gal)	ILW-11 (Ci/gal)
Gross α	$<1.7 \times 10^{-8}$	1.5×10^{-7}	a	5.5×10^{-8}
^{90}Sr	3.7×10^{-4}	1.8×10^{-4}	5.43×10^{-4}	5.8×10^{-4}
^{137}Cs		2.1×10^{-3}		2.5×10^{-3}
^{106}Ru	a	2.6×10^{-3}	a	a
^{134}Cs	a	3.2×10^{-5}	a	a
^{60}Co	a	2.5×10^{-5}	a	a
Na	24 mg/ml	-	22 mg/ml	35.3 mg/ml
pH	12.3	12.6	11.4	10.0

[a]Not analyzed.

Table 16. Measured Noise Levels

Location	OSHA Permissible Exposure (hr per 8-hr shift)	
	Blending	Injection
Scales	8+	-
Bin 1	8+	8+
Bin 2	8+	6
Bin 3	6	1.75
Bin 4	5.3	1.75
Operating room	8+	8+
Injection pump	8+	0.5
Cement truck cab	1.6	-
Window (north)	-	4
Window (south)	-	0.75
Office	-	8+

8.6 Pressure Measurements for Monitoring Wells

The surface pressures of the rock cover monitoring wells were measured during each injection. The results are shown in Figs. 34-37 and summarized in Table 17. These results indicate that there is probably a close correlation between a positive pressure change in a monitoring well and the direction of travel of the grout sheet. There are some discrepancies and some ambiguities; however, in general, the response of these wells seems to provide an immediate indication of grout sheet movement (information for which there is a real need).

8.7 Strain-Gage Readings

The strain gages mounted on the plug container were monitored during Injections ILW-8 and ILW-10. The results indicated that the static stresses were small and that the dynamic stresses were even smaller. Failure of this piece of equipment due to fatigue does not appear to be a matter for serious concern.

8.8 Water Acceptance Rate for Rock Cover Monitoring Wells

A network of rock cover monitoring wells has been installed in the vicinity of the disposal site. These wells are cased and cemented to a depth of 500 ft and have 100 ft of open hole below the cased section. One of the uses of these wells is to verify the continued impermeability of the shale formation lying above the waste disposal zone and thus show that continued uplift of this formation is not opening pathways in the shale through which surface water could migrate to the waste disposal zone. The impermeability of the shale beneath these wells is tested by determining the rate at which water at a surface pressure of 75 psi can be pumped into the shale surrounding the 100 ft of open hole that is beneath each well. The change in the acceptance rate of these wells has been slight and has shown no consistent trend. The acceptance rate tests are repeated at about every fourth injection.

Three types of response of the wells have been observed. First, the well may take no measurable volume of water. Second, the well may take a

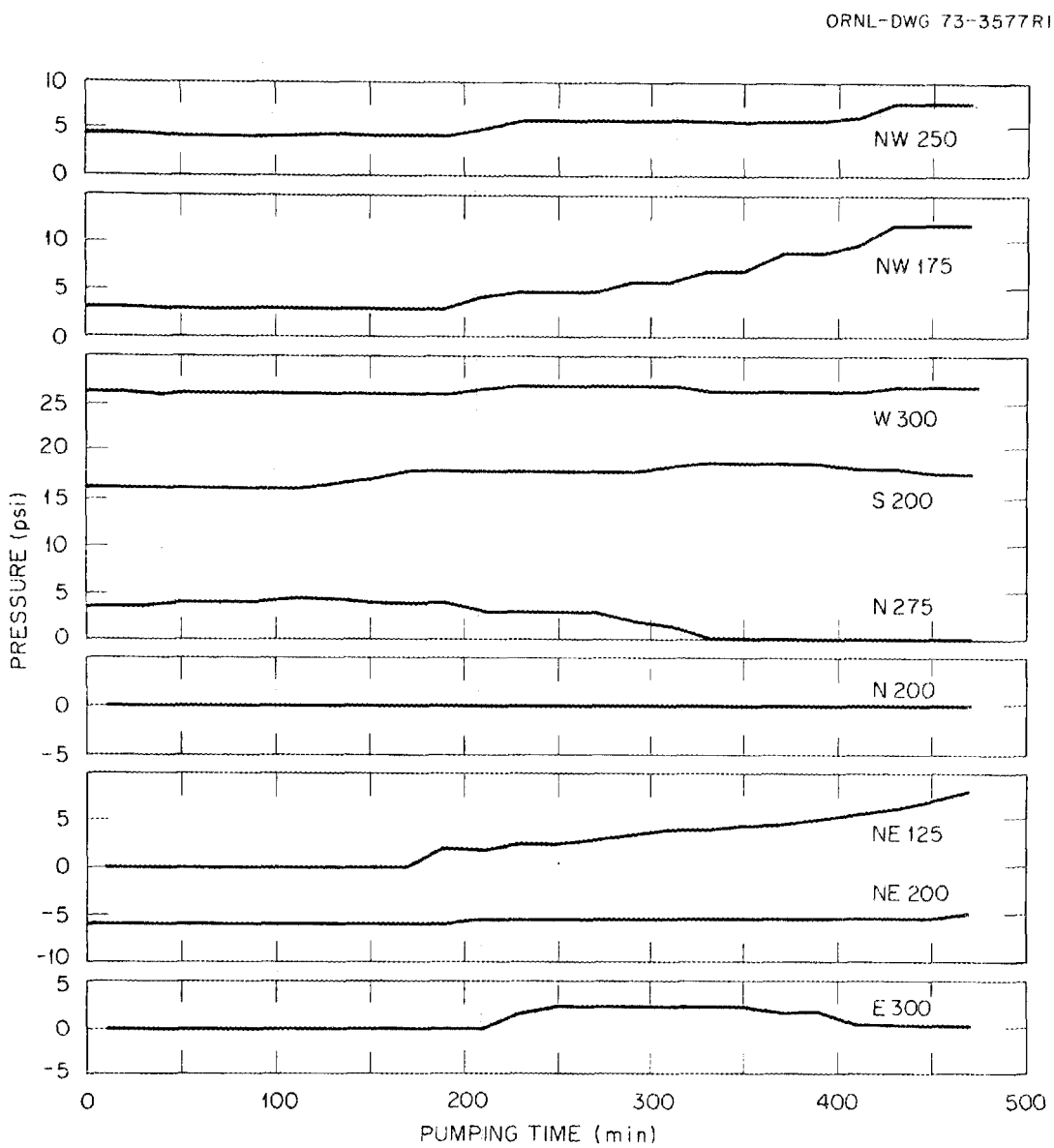

Fig. 34. Pressure Changes in Rock Cover Wells, Injection ILW-8 (September 29, 1972).

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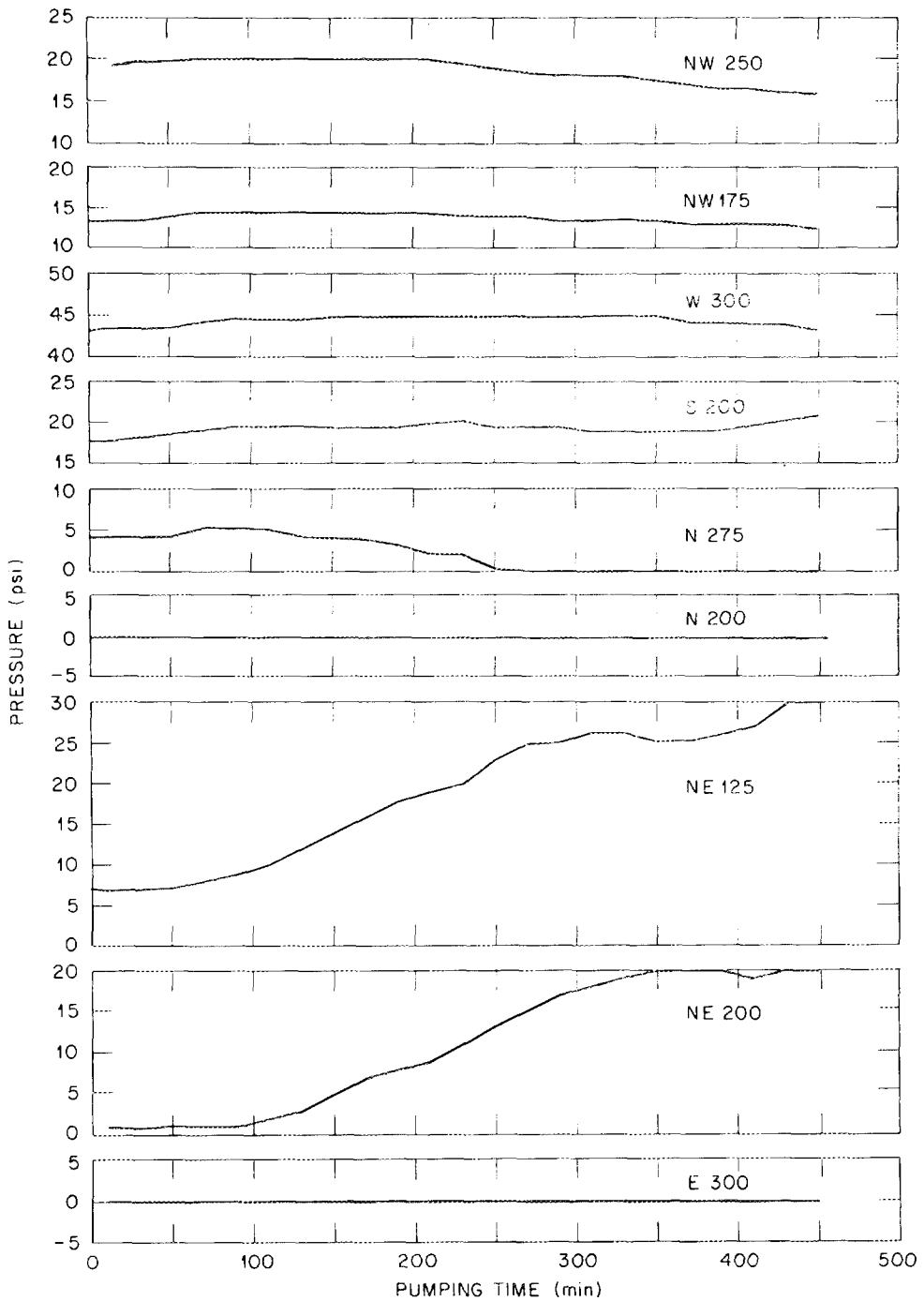

Fig. 35. Pressure Changes in Rock Cover Wells, Injection ILW-9 (October 17, 1972).

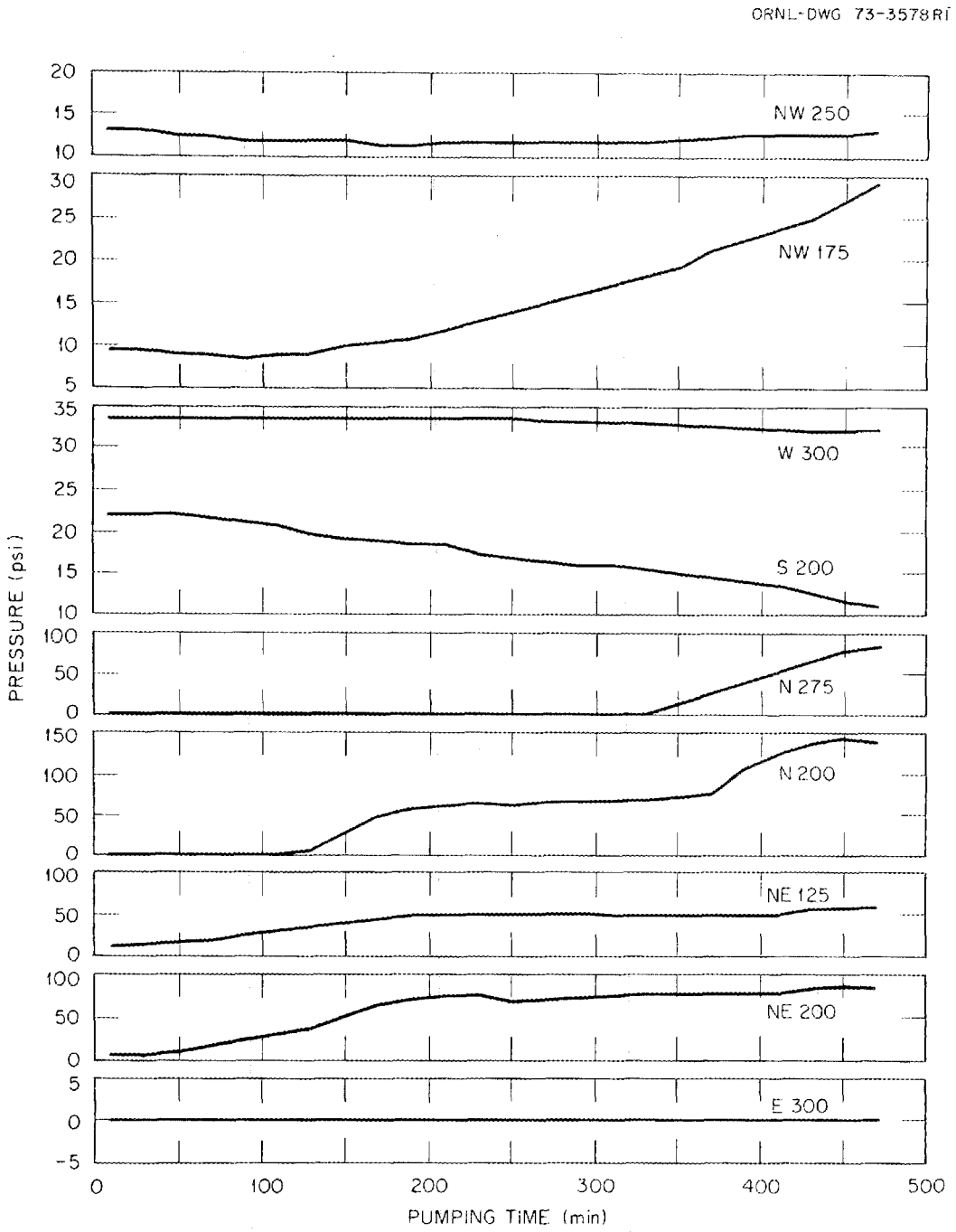

Fig. 36. Pressure Changes in Rock Cover Wells, Injection ILW-10 (November 8, 1972).

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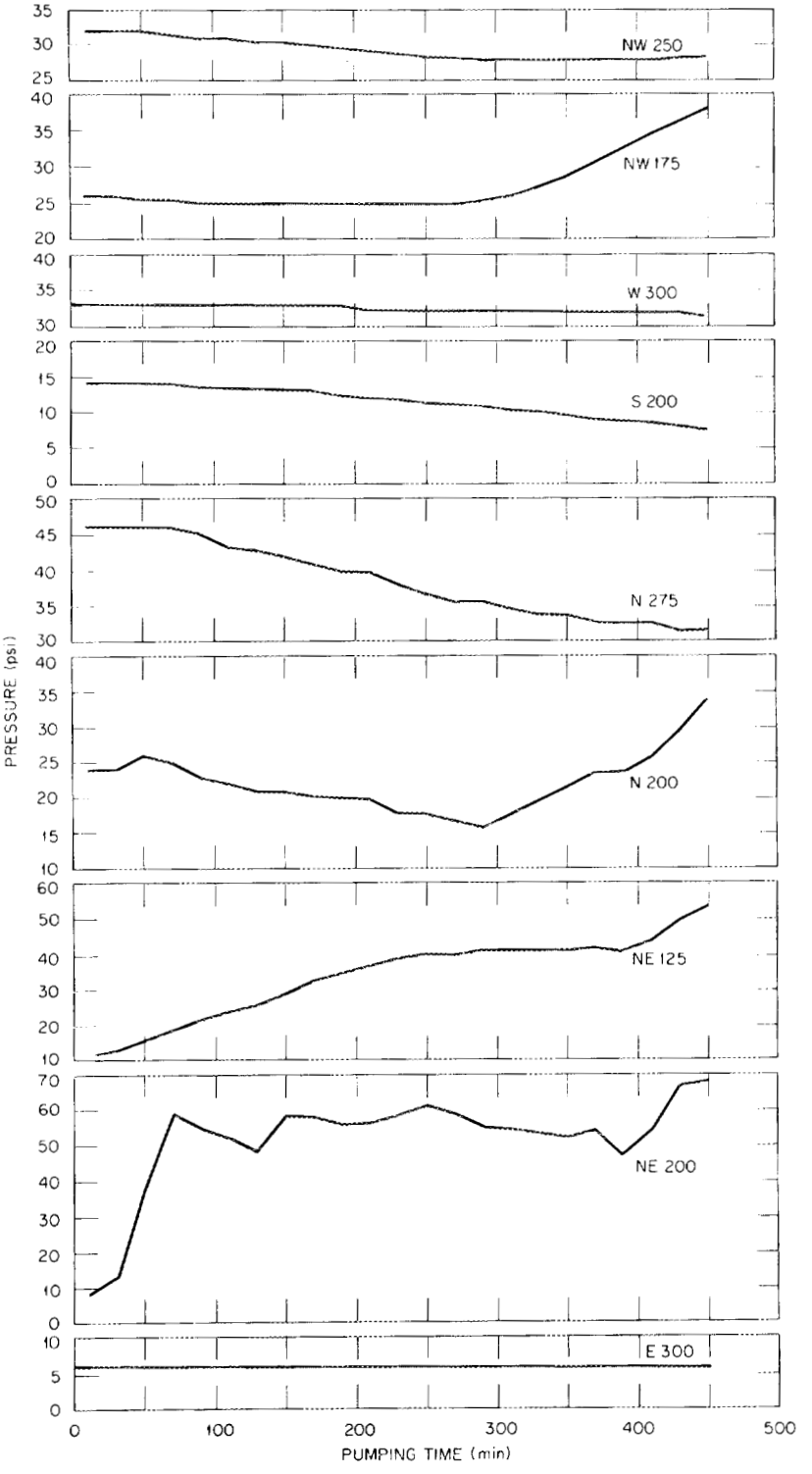

Fig. 37. Pressure Changes in Rock Cover Wells, Injection ILW-11 (December 5, 1972).

Table 17. Summary of Well Pressure Measurements

Logging Results		Pressure Indications			
Positive	Negative	Positive	Negative	Ambiguous	Conclusions
			ILW-8		
NW100 S100	W300 N100 N150 NE125 E320 S220	NW175 NW250 NE125	N275 N200 NE200	W300 S200 E300	Both measurements indicate grout sheet went NW. Did not go far S or E; did not go N. NE125 results are conflicting.
			ILW-9		
W300 N150 S100	NW100 N100 NE125 E320 S220	NE125 NE200 S200	E300 N200 N275 NW250	W300 NW175	Pressure measurements indicate a NE grout sheet movement, somewhat S, perhaps W. Did not go N or NW. Logging indicates predominantly W. NE125 results are conflicting.
			ILW-10		
W300 NW100 N150 N100 NE125	E320 S100 S220	NW175 N275 N200 NE125 NE200	W300 S200 E300	NW250	Pressure measurements indicate grout went N and NE and somewhat NW. Did not go S. Logging indicates N and NW, not S.
			ILW-11		
NW100 N150 N100 NE125 S100	W300 E320 S220	NW175 N200 NE125 NE200	NW250 W300 S200 N275 E300		Pressure measurements indicate grout went somewhat N, somewhat NW, strongly NE. Did not go S or W. Logging indicates N, NE, and NW.

small amount of water in the first hour of the test and an even smaller amount of water during the second hour. Third, the well may take the same small volume of water during the second hour as during the first. In cases where the volume decreases during the second hour, the fractures in the shale accepting the water are believed to be of very limited extent. In cases where the volume accepted in the second hour is the same as in the first, limited experience suggests that the rate of acceptance will decrease with longer pumping. The tests are now terminated after 2 hr of pumping, which appears to be a sufficiently long period to reveal any marked increase in the permeability of the shale. The results of the tests to date are given in Table 18.

8.9 Uplift Measurements

The surface uplift at the injection site was remeasured after Injection ILW-11 by a team from the National Ocean Survey. The results of this survey are shown in Fig. 38. The uplift produced by this series of injections appears to be regular and proportional to the distance from the injection well, as was the case for previous injections.

9. SUGGESTIONS FOR IMPROVEMENT

9.1 Compatibility of Waste and Blended Solids

Laboratory tests have shown that not all waste and cement mixes are compatible, and that wastes which differ comparatively little in chemical composition can produce grouts with drastically different properties. Understanding of the phenomena involved is limited. It seems prudent, therefore, to continue testing the blended solids prior to each injection to avoid unpleasant surprises. Such testing was done in this series of injections with synthetic waste solutions. One further step seems desirable, however. A test should be made to determine the compatibility of the blended solids and actual waste solution. Such a final "hot" test would remove doubts about sampling errors, analysis errors, or failure to consider the effect on grout properties of some waste constituent in very low concentration.

Table 18. Water Acceptance Rate (in gph) of Rock Cover Monitoring Wells

Well	August 1964	May 1965	August 1969	July 1970	May 1973
N100					
First hour	5	Converted to logging well			
Second hour	4				
E300				None	None
W300					
First hour				None	0.1
Second hour					None
N275					
First hour			None		0.05
Second hour					0.05
NW250					
First hour			0.5	0.25	0.3
Second hour			0.5	0.25	0.3
NE200					
First hour			0.4		0.5
Second hour			0.4		0.5
S200					
First hour				0.9	0.75
Second hour				None	0.5
N200E					
First hour	5	1.8	1.25	0.75	1.2
Second hour	3.5	1.6	1.0	0.5	1.2
NE125					
First hour		1.5	2.5		1.2
Second hour		0.7	2.0		1.2
NW175					
First hour		None	1.0		1.5
Second hour			1.0		1.5

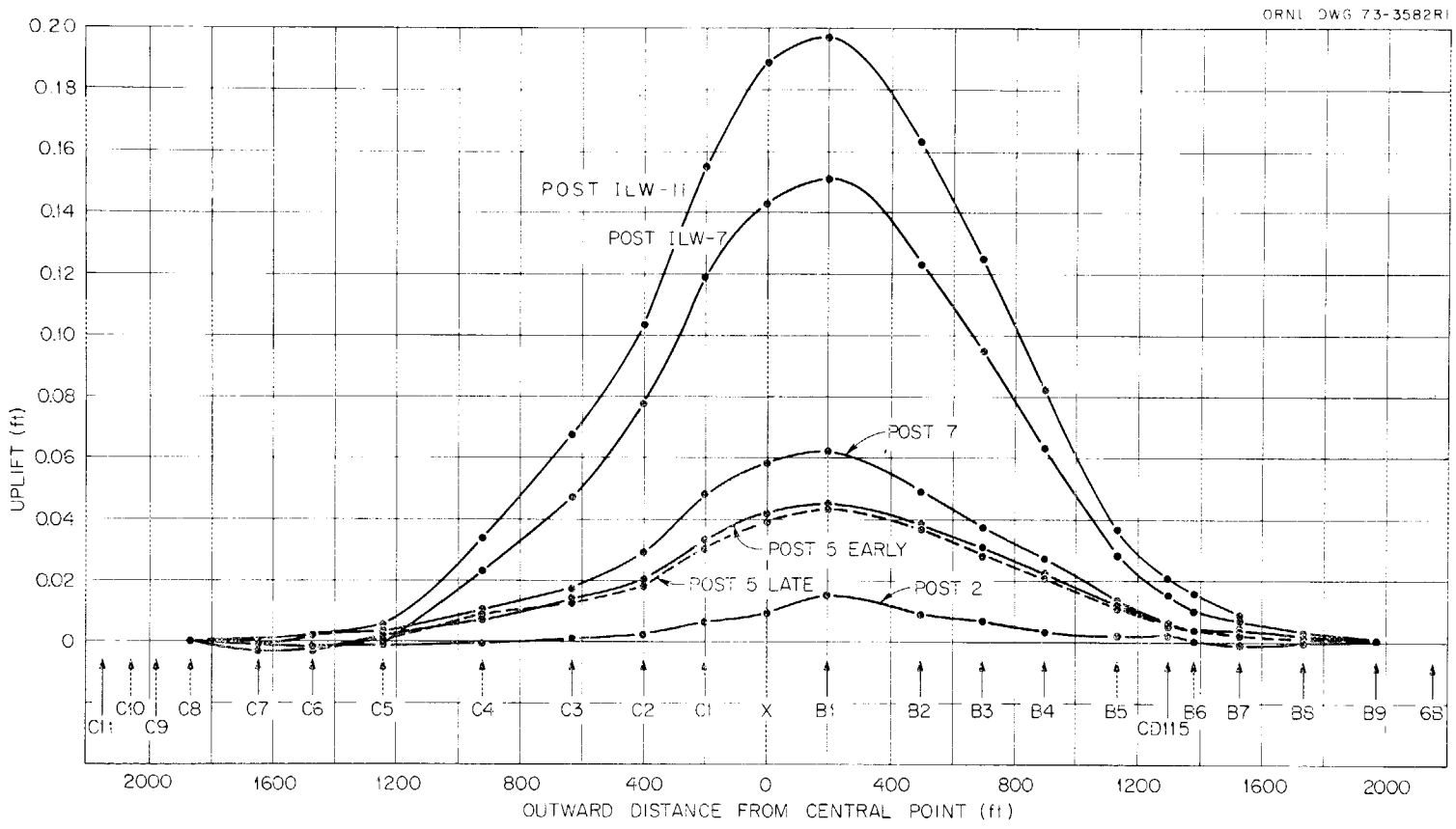

Fig. 38. Surface Uplift at Fracturing Site.

The reason for the wide variation in the properties of grouts made from solids mixes blended on different days should be determined. Laboratory work indicates that more than one phenomenon is involved; more work is needed to isolate the critical effects.

Most of the laboratory work on the properties of waste grouts has been done with a synthetic waste solution. The analysis of this waste was based on a sample that is taken from a 50-ft-diam tank and, obviously, may not have been typical of the tank contents as a whole. A composite sample of the waste that is pumped to the fracturing site would be more representative; on the other hand, such a sample is usually not available until immediately before the injection, which is not early enough to be useful. If the waste solution were pumped to the fracturing site several weeks before the injection, an analysis of the composite sample could be used as the basis for the formulation of the synthetic waste solution and uncertainty about the sample being representative would be reduced.

9.2 Bleedback

The bleedback tests that were made in connection with this series of injections indicate that the bleedback volume would be much smaller if the bleedback operation were not started until several months after the injection. Unless other considerations prohibit such a delay, it should become standard procedure after future injections.

The hypothesis that bleedback water is squeezed from the pores of the grout as the grout sheet is compressed during the bleedback operation should be investigated. Grouts with higher compressive strength may be required.

9.3 Waste Injections

The Densometers were not reliable indicators of the mix ratio of the grout during this series of injections. In addition, they are difficult to keep operating satisfactorily; the lines to and from the Densometers frequently plug, and the hydraulic system that drives the Densometer pump is not trouble-free.

The difficulties that were experienced with sticky solids in Injection ILW-11 point up the necessity of having these solids free-flowing. Unfortunately, the cause of the difficulty is not known. It should be investigated.

An appreciable fraction of the solution injected during the series of runs described in this report was contaminated water (from previous washup operations, etc.). This water could be pumped back to the tank farm in Bethel Valley and mixed with the unconcentrated ILW. Such a transfer requires patrolling of the transfer line, as well as other efforts, but is probably preferable to injecting this volume of very dilute waste. If transfer to Bethel Valley should prove to be impractical, some effort should be made to minimize the volume of waste water (e.g., by keeping rain out of the waste pits).

In general, comparatively few difficulties were experienced during this series of injections. The grout was much more fluid than in preceding injections, even though the solids/waste mix ratio was considerably higher than that used previously. As a result of this decrease in grout viscosity the mixing operation was much easier, no trouble was experienced with grout gelling in the sump tub, and the operation of the injection pump was much smoother. The principal problems that were encountered in these injections primarily involved compatibility of the solids mix and the waste solution. To some extent these problems have probably been present, but unrecognized, all along.

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