

# VELA UNIFORM PROGRAM

## PROJECT DRIBBLE

# SALMON EVENT

TATUM SALT DOME, MISSISSIPPI

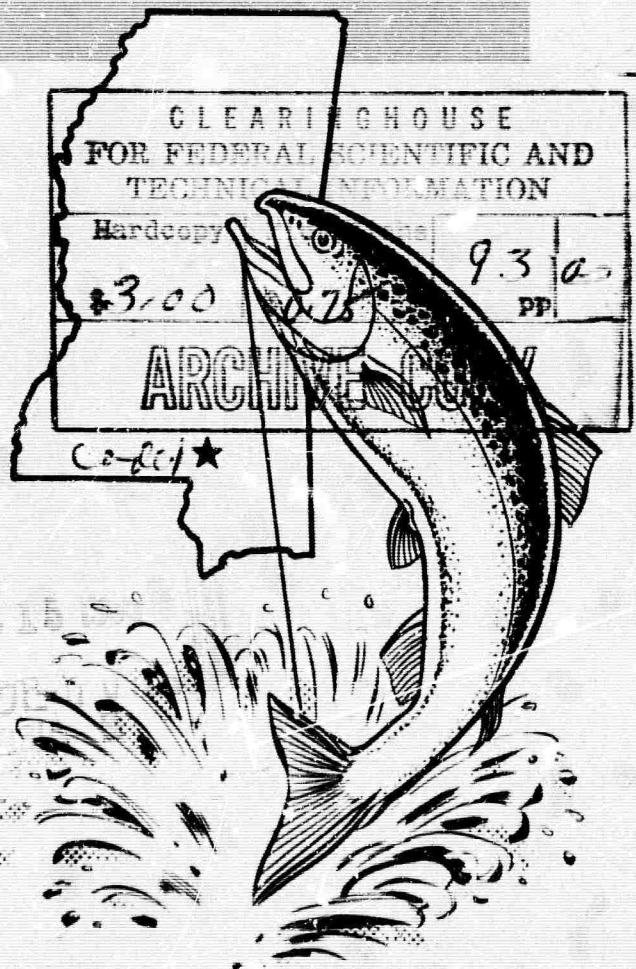
22 OCTOBER 1964

part of an experiment in seismic decoupling at the nuclear level

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## Laboratory Design, Analysis, and Field Control of Grouting Mixtures Employed at a Nuclear Test in Salt

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PROJECT DRIBBLE  
SALMON EVENT

LABORATORY DESIGN, ANALYSIS, AND FIELD CONTROL  
OF GROUTING MIXTURES EMPLOYED AT A NUCLEAR  
TEST IN SALT

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## ABSTRACT

In the Project DRIBBLE Salmon Event, the first of three planned events for the DRIBBLE program, a 5-kt nuclear device was detonated near the bottom of a 2,720-foot-deep hole drilled vertically into a salt dome in Mississippi. This report describes work by the U. S. Army Engineer Waterways Experiment Station in (1) furnishing grouting consultant services and technical assistance in the field during grouting operations, (2) conducting stemming studies for the device emplacement hole, (3) developing formation-matching grouts for use in grouting instruments in place in deep drilled holes, (4) providing instruments for hole temperature determinations, and (5) making physical tests on salt cores from the project site. Based on the results of this investigation, the following conclusions are made.

1. Grout mixtures were successfully developed to meet all job requirements. Modifying mixtures to meet depressed temperature requirements did not appreciably alter the desired physical properties of the mixtures.

2. With the exception of one hole, all instrument holes were successfully grouted. Difficulties were experienced in other holes; however, various remedial actions solved these problems.

3. The stemming operation for the device hole was highly successful in all respects.

4. Modifications and the addition of supplemental mixing equipment to

the grouting systems considerably improved the quality control of the grout mixture. This improved quality control is believed to have been largely responsible for the successful grouting of the device and instrument holes.

## PREFACE

The work reported herein in connection with Project DRIBBLE was performed for the U. S. Atomic Energy Commission under the direction and coordination of the University of California Lawrence Radiation Laboratory, and was sponsored by the Advanced Research Projects Agency, Department of Defense. The laboratory work performed by the U. S. Army Engineer Waterways Experiment Station (WES) in connection with this project, particularly the Salmon Event, was accomplished during the years 1962 through 1964. The field work was conducted during the winter and summer of 1963, and during the summer and fall of 1964. The laboratory tests of cores from the project site, performed in 1962, were reported in "Project DRIBBLE, Petrographic Examination and Physical Tests of Cores, Tatum Salt Dome, Mississippi," Technical Report No. 6-614, January 1963, U. S. Army Engineer Waterways Experiment Station.

Excellent cooperation, logistic support, and assistance were furnished WES by the organizations and personnel participating in the Salmon Event tests. Among those organizations were: U. S. Atomic Energy Commission; University of California Lawrence Radiation Laboratory; Holmes and Narver, Inc.; Sandia Corporation; Stanford Research Institute; Fenix & Scisson, Inc.; and Reynolds Electrical & Engineering Co., Inc.

The WES phase of the overall project was performed under the supervision of Messrs. T. B. Kennedy, Chief of the Concrete Division; J. M. Polatty; W. O. Tynes; R. L. Curry; E. E. McCoy; K. L. Saucier; B. R. Sullivan; and R. A. Bendinelli; and Mrs. K. Mather. This report was prepared by Mr. Bendinelli. Appendix A was prepared by Mr. B. J. Houston who supervised development of the instruments discussed in Appendix A.

Directors of WES during the investigation reported herein and during the preparation of this report were Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswald, Jr., CE. Mr. J. B. Tiffany was Technical Director.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 OBJECTIVES

In the Salmon Event, one of three events planned by the U. S. Atomic Energy Commission for Project DRIBBLE, a 5-kt nuclear device was detonated on 22 October 1964 near the bottom of a hole 2,720 feet deep and 17.5 inches in diameter drilled in the Tatum Salt Dome located approximately 20 miles southwest of Hattiesburg, Mississippi (Figure 1.1). The principal objective of the event as a part of the DOD Vela Uniform program was to obtain information in connection with the detection of underground nuclear detonations.

#### 1.2 WES PARTICIPATION IN SALMON EVENT

1.2.1 Grout Design and Other Proposed Activities. Prior to the Salmon Event, the U. S. Army Engineer Waterways Experiment Station (WES) was requested to develop a special grout mixture to be used for embedding scientific instruments in holes drilled from the surface to varying depths at varying distances from surface ground zero (SGZ), and for stemming the device emplacement hole at station 1-A. When hardened, this grout was to match the in situ physical characteristics of selected salt core specimens obtained from the test site and, in addition, be pumpable, shrinkage resistant, and have adequate bond-to-salt strength. WES had successfully developed similar mixtures for the Projects COWBOY and GNOME tests conducted in salt domes located near Winnfield, Louisiana, and Carlsbad, New Mexico. WES was also requested to (1) perform extensive laboratory tests to determine various physical and chemical properties of selected salt-core

specimens obtained from the project site, (2) perform laboratory temperature studies in connection with instrumenting deep drilled holes, (3) conduct laboratory studies of stemming materials and procedures for stemming the device emplacement hole, (4) provide consultant services and technical assistance in the field in connection with grouting operations, and (5) perform such grout studies as might be necessary to meet immediate job requirements.

1.2.2 Actual Scope of Participation. The WES was responsible for and furnished the following laboratory and field support for the Salmon Event:

1. Performed physical tests on selected salt cores obtained from exploratory holes drilled at the test site.
2. Developed in the laboratory (a) grout mixtures for matching the in situ physical characteristics of the salt, (b) a grout mixture for matching a sand and shale formation overlying the salt formation, (c) a salt-matching grout mixture having a low heat of hydration for use as a stemming plug for the hole containing the nuclear device, and (d) a grout mixture for stemming instrument holes above the salt formation.
3. Conducted studies of the suitability of pea gravel aggregates from five sources for use as a stemming material above the grout stemming plug in the station 1-A hole.
4. Designed special microswitches for determining the progress and adequacy of pea gravel stemming of the station 1-A hole.
5. Conducted both laboratory and field temperature studies of grouts in connection with down-hole instrumentation.
6. Performed miscellaneous laboratory work to (a) determine sonic velocity of drilling mud and casing grout, (b) investigate instrument cable

deformation, and (c) develop bypasses for grout around instrument canisters in holes.

7. Provided consultant services and technical assistance at the project site in connection with (a) determining the capability of two cementing companies to produce quality grout, and (b) quality control of grout during grouting of the instrument and device-emplacment holes.

8. Provided down-hole instrumentation for (a) determining adequacy of instrument and device-emplacment grouting, (b) monitoring temperature of emplaced grouts, and (c) determining the adequacy of the pea gravel stemming of the device hole.

9. Cast grout specimens in the field for laboratory testing on shot date.

10. Conducted postshot work which included (a) laboratory testing of the field-cast grout specimens on shot date, and (b) preparing this report.

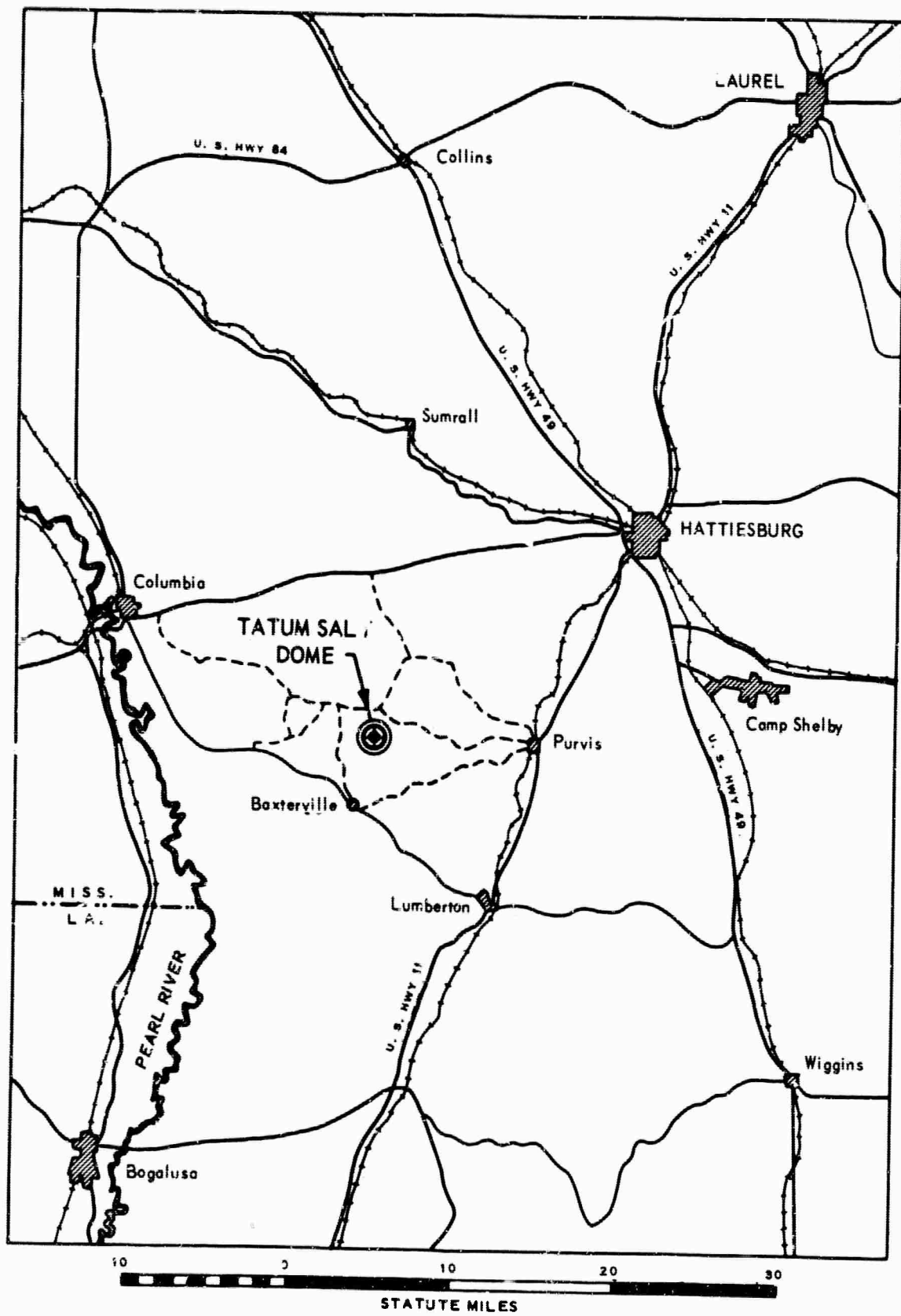


Figure 1.1 Vicinity map.

## CHAPTER 2

### GROUT MIXTURES

#### 2.1 DESIGN CRITERIA

Grout mixtures were required that would match as nearly as possible certain physical properties of the salt formation in which instruments for measuring acceleration, velocity, displacement, and strain were to be embedded in vertically drilled holes by means of grouting. Design criteria for the salt-matching grout were based on the results of physical tests performed on the salt-core specimens (Tables 2.1, 2.2, 2.3). The principal physical properties of the in situ salt that were to be matched as nearly as possible were an ultrasonic pulse velocity of 13,755 ft/sec, a unit weight of approximately 135 pcf, and a compressive strength of 3,350 psi. Later, during the course of the project field work, the salt-matching grout mixture was adjusted to depress high grout temperatures resulting from cement heat-of-hydration. A mixture was also developed for embedding instruments in a sand-shale formation overlying the salt formation. This mixture was required to have, when hardened, a sonic pulse velocity of approximately 6,700 ft/sec and a unit weight of approximately 100 pcf. Several other grout mixtures were developed for use as "butter" grout and for stemming above the emplaced instrumentation.

#### 2.2 MATERIALS AND LABORATORY MIXTURES

The following materials were used in studies for developing the various grout mixtures required for the project prior to and during field operation:

Material	Specific Gravity	Unit Weight
		pcf
Portland cement, type I	3.15	196.24
Silica sand (20-40 gradation)	2.65	165.10
Gel (bentonite)	2.36	147.03
Fine salt <sup>a</sup>	2.25	140.18
Fly ash	2.21	137.68
Aluminum powder <sup>b</sup>	--	--
Retarder <sup>c</sup>	--	--

<sup>a</sup> Used for brining grout-mixture water.

<sup>b</sup> A mixture of finely granulated and leafing types of aluminum powder used to offset the shrinkage of the mixture.

<sup>c</sup> A lignin-base solution.

The proportions of the six mixtures designed in the laboratory to meet project grouting requirements are shown in Table 2.4.

### 2.3 PHYSICAL TESTS OF LABORATORY MIXTURES

Laboratory specimens cast from mixtures 1 through 6 (Table 2.4) were tested for the physical properties and at the ages indicated in the following tabulation.

Each value represents the average of three specimens.

Mix- ture No.	Compressive Strength				Unit Weight				Ultrasonic Pulse Velocity			
	3 Days	7 Days	14 Days	28 Days	3 Days	7 Days	14 Days	28 Days	3 Days	7 Days	14 Days	28 Days
	psi				pcf				ft/sec			
1	1,770	2,830	2,880	3,175	130.58	131.64	131.64	131.70	6,500	11,440	11,686	11,976
2	1,170	1,470	1,690	2,045	128.28	128.46	127.78	127.65	6,500	10,638	10,883	11,364
3	1,220	2,120	2,385	2,680	110.96	112.51	113.01	113.32	6,660	9,180	9,712	10,080
4	420	600	845	1,410	102.17	102.17	101.67	101.05	5,780	7,060	7,718	8,333
5	315	520	685	1,000	92.45	93.14	93.45	92.76	5,480	5,110	6,769	7,721
6	590	880	1,160	1,560	101.61	101.36	101.49	100.68	7,140	7,680	8,065	8,475

TABLE 2.1 RESULTS OF PHYSICAL TESTS ON SALT CORES

All procedures except those for determining specific gravity by bulk keroser displacement and apparent specific gravity were taken from American Petroleum Institute Recommended Practice for Core Analysis Procedure. Specific gravity determined by bulk kerosene displacement and apparent specific gravity were determined using the method described in CPD-C 107-60 in Handbook for Concrete and Cement, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Core No.	Length of Core	Diameter of Core	Specific Gravity		Porosity	Residual Liquid Saturation	
			Bulk Mercury Displacement	Bulk Kerosene Displacement		Oil	Total Water
Hole WP-1:							
	feet	inches			pct	pct of pore space	
DC-64	1,553.5 - 1,555.0	5.0	2.167	2.205	3.00	0	1.7
DC-14	1,672.0 - 1,673.6	5.0	2.298	2.194	5.30	0	1.1
DC-16	1,822.5 - 1,824.2	5.0	2.317	2.207	3.30	0	1.5
DC-25	1,947.2 - 1,949.0	5.0	2.297	2.205	--	--	--
DC-26	1,994.5 - 1,995.6	5.0	2.322	2.211	--	--	--
DC-22	2,097.3 - 2,099.0	5.0	2.291	2.200	--	--	--
DC-2	2,249.0 - 2,252.0	5.0	2.221	2.198	--	--	--
DC-4	2,341.0 - 2,344.0	5.0	2.206	2.196	2.64	0	0
DC-6	2,445.0 - 2,448.0	5.0	2.200	2.181	--	--	--
DC-2	2,459.5 - 2,463.0	5.0	2.210	2.186	4.71	0	0
DC-11	2,613.0 - 2,616.0	5.0	2.215	2.206	3.36	0	0
DC-10	2,656.0 - 2,659.0	5.0	2.230	2.223	2.76	0	0
Hole WP-4:							
MXC-8	2,317.0 - 2,318.0	2.125	2.207	2.219	2.05	0	0
MXC-9	2,402.0 - 2,403.0	2.125	2.186	2.189	1.53	0	0
MXC-23	2,476.0 - 2,477.4	2.125	--	2.212	--	--	--
MXC-25	2,533.0 - 2,534.0	2.125	--	2.204	--	--	--
MXC-13 <sup>b</sup>	2,698.5 - 2,699.5	2.125	2.141	2.183	8.59	0	0
			Average 2.206				

<sup>a</sup> Values shown are considered to be representative of specific gravity of salt formation which averaged 2.206.  
<sup>b</sup> Core 13 was fractured, causing permeability and porosity to be unusually high.

TABLE 2.2 PULSE VELOCITIES OF SALT CORES

Core No.	Core Depth	Specimen Diameter	Specimen Length	Pulse Velocity	
				Ultrasonic <sup>b</sup> $v_p^c$	Sonic <sup>d</sup> $v_s^d$
	feet	inches <sup>a</sup>	inches <sup>a</sup>	ft/sec	
Hole WP-1:					
C-1C	2,244.0 - 2,247.0	5.00	12.50	13,390	--
DC-1D	2,244.0 - 2,247.0	5.00	12.50	13,355	--
DC-2	2,249.0 - 2,252.0	5.00	30.00	--	12,710
DC-2B	2,249.0 - 2,252.0	5.00	10.00	12,220	--
DC-2C	2,249.0 - 2,252.0	5.00	10.00	12,705	--
DC-3	2,393.0 - 2,397.0	5.00	20.00	13,380	11,585
DC-7	2,545.0 - 2,548.0	5.00	20.00	13,845	12,695
DC-11	2,613.0 - 2,616.0	5.00	20.00	13,735	12,600
DC-12	2,700.0 - 2,703.0	5.00	20.00	13,690	12,745
DC-14	1,672.0 - 1,673.6	5.00	20.00	14,860	13,195
DC-14C	1,672.0 - 1,673.6	5.00	12.88	--	--
DC-15B	1,720.0 - 1,721.5	5.00	12.62	--	--
DC-16	1,822.5 - 1,824.2	5.00	20.00	14,955	12,910
DC-18B	1,679.0 - 1,680.5	5.00	12.38	--	--
DC-19B	1,723.2 - 1,724.7	5.00	12.31	--	--
DC-22	2,097.3 - 2,099.0	5.00	20.00	14,505	13,055
DC-23B	2,196.5 - 2,198.0	5.00	12.50	--	--
DC-24	1,990.5 - 1,992.3	5.00	20.00	15,000	12,930
DC-25	1,947.2 - 1,949.0	5.00	20.00	14,910	12,700
DC-30B	2,239.8 - 2,241.5	5.00	12.38	--	--
DC-33B	2,151.8 - 2,153.5	5.00	12.50	--	--
DC-40A	2,216.5 - 2,218.0	5.00	12.59	--	--
DC-64	1,553.5 - 1,555.0	5.00	19.00	14,820	13,080
Box 116	Unknown	5.00	18.25	13,945	12,390
Box 225	Unknown	5.00	16.50	13,195	10,865
Hole WP-4:					
NXC-8	2,317.0 - 2,318.0	2.06	10.50	14,035	--
NXC-9	2,402.0 - 2,403.0	2.06	10.56	13,510	--
NXC-10	2,603.5 - 2,604.5	2.06	10.56	13,810	--
NXC-11	2,495.5 - 2,496.5	2.06	10.56	13,270	--
NXC-12	2,647.5 - 2,648.6	2.06	10.56	12,805	--
NXC-13	2,698.5 - 2,699.5	2.06	10.56	12,645	--
				Average 13,775	

<sup>a</sup> Dimension used in calculations.

<sup>b</sup> Values shown are considered to be representative of ultrasonic pulse velocity of salt formation which averaged 13,755 ft/sec.

<sup>c</sup> Determined by soniscope (CRD-C 51-57).

<sup>d</sup> Calculated from 21  $f_p$ .

TABLE 2.3 RESULTS OF COMPRESSIVE STRENGTH TESTS OF SALT CORES (HOLE WP-1)

Core No.	Core Depth	Specimen Dimensions		Compressive Strength
		Diameter	Length	
	feet	inches		psi
4B	2,341.0 - 2,344.0	4.94	10.60	3,590
4D	2,341.0 - 2,344.0	4.94	10.50	3,550
44B	2,398.8 - 2,400.5	4.94	10.59	3,700
41B	2,406.0 - 2,407.2	4.96	10.65	3,660
8C	2,459.5 - 2,463.0	4.97	10.46	3,200
8B	2,459.5 - 2,463.0	4.96	10.63	3,230
11C	2,613.0 - 2,616.0	4.96	10.48	3,050
11D	2,613.0 - 2,616.0	4.96	10.52	3,120
12B	2,700.0 - 2,703.0	4.96	10.50	3,110
12C	2,700.0 - 2,703.0	4.97	10.47	3,300

TABLE 2.4 MIXTURES FOR PROJECT GROUTING REQUIREMENTS

Material	Proportions for a One-Bag Batch	
	Solid Volume	Dry Batch Weight
	ft <sup>3</sup>	pounds (SSD)
Mixture No. 1 (to match salt):		
Portland cement, type I	0.479	94.0
Silica sand	0.908	150.0
Fine salt	0.137	19.2
Gel (bentonite)	0.027	3.8
Water (iced)	0.830	51.7
Retarder	--	(85 grams)
Aluminum powder	--	(2 grams)
Mixture No. 2 (to match salt and depress temperature):		
Portland cement, type I	0.335	65.7
Fly ash	0.144	19.8
Silica sand	0.964	160.0
Fine salt	0.138	19.4
Gel (bentonite)	0.023	3.4
Water (iced)	0.809	50.4
Aluminum powder	--	(1.4 grams)
Mixture No. 3 (used for butter grout in salt formation):		
Portland cement, type I	0.479	94.0
Fine salt	0.137	19.2
Gel (bentonite)	0.027	3.8
Water (iced)	0.830	51.7
Retarder	--	(85 grams)
Aluminum powder	--	(2 grams)
Mixture No. 4 (used for butter grout in salt formation and to depress temperature):		
Portland cement, type I	0.239	46.9
Fly ash	0.239	32.9
Gel (bentonite)	0.033	4.8
Fine salt	0.142	19.9
Water (iced)	0.833	51.9
Aluminum powder	--	(2 grams)
Mixture No. 5 (to match shale and sand):		
Portland cement, type I	0.239	46.9
Fly ash	0.239	32.9
Gel (bentonite)	0.044	6.4
Retarder	--	(42 grams)
Water (iced)	1.024	63.8
Aluminum powder	--	(5 grams)
Mixture No. 6 (used as stemming grout inside casings):		
Portland cement, type I	0.239	46.9
Fly ash	0.239	32.9
Gel (bentonite)	0.033	4.8
Retarder	--	(42 grams)
Water (iced)	0.872	54.3

CHAPTER 3  
TEMPERATURE STUDIES

3.1 FIELD STUDIES, HOLE WP-1

During the fall of 1962, field studies were conducted to determine the peak temperature of mixture 1 when emplaced. An exploratory hole (WP-1), 3,510 feet deep and approximately 8 inches in diameter, was used for this study. Thermistors were lowered into the hole to the depths noted in Figure 3.1 on a 1/2-inch steel cable by means of a winch. Under the supervision of WES, the mixture was mixed and pumped down-hole through a 1-inch-ID plastic hose by the Dowell Company. The hose was also lowered on the 1/2-inch steel cable. Table 3.1 shows the temperature data obtained. Following the completion of the studies, hole WP-1 was backfilled with mixture 1 to the 2,761-foot depth.

3.2 LABORATORY STUDIES, GROUT MIXTURE

Caliper logs of the instrument holes indicated that overdrilling and erosion of the salt were resulting in appreciable increases in hole diameter. Concern was expressed that excessive temperatures might occur in holes having diameters larger than designed because the increased grout mass might produce a heat-of-hydration above acceptable levels. These temperature limitations were applicable to both the instrumentation holes and the nuclear device hole.

A series of laboratory tests were conducted in which down-hole grouting was simulated and the mixtures were modified by reportioning to depress heat-of-hydration temperatures to acceptable levels and still not compromise the desired physical properties.

The temperature studies for hole WP-1 had indicated a temperature of 7 F at the 2,760-foot depth. Using this temperature as the control, the following grout mixtures were tested under field-simulated conditions: (1) mixture 1; (2) mixture 1 using iced mixing water; (3) mixture 2, replacing 30 percent of cement content of mixture 1 with fly ash, and using iced mixing water; and (4) mixture 4, containing 50 percent cement and 50 percent fly ash, and using iced mixing water.

Mixture 1 was cast in an 8-inch-diameter hole formed in the center of a 2-1/2-foot grout cube and in two 18-inch-diameter holes also formed in a 2-1/2-foot grout cube. Mixtures 2 and 4 were cast in 18-inch-diameter holes formed in 2-1/2-foot grout cubes. All cubes containing the test mixtures were tested in a controlled-temperature room with the temperature at 117 F. The temperature of the mixing water in each mixture, resulting peak temperature, and time of peaking are given in the following tabulation.

Mixture No.	Hole Diameter	Temperature of Mixing Water	Peak Temperature	Peaking Time
	inches	F	F	hours
1	8	80 ± 2	144	20
1	18	80 ± 2	171	15
1	18	58 ± 2	151	20
2	18	58 ± 2	135	20
4	18	58 ± 2	130	30

Figure 3.2 shows temperature versus time data for the mixtures tested.

These studies indicated that in holes having diameters in excess of 8 inches where grouting is required at depths approximately 2,000 feet and

deeper, grouts should be mixed with iced water, or cement-replacement materials, or both, to insure that the heat-of-hydration does not result in objectionable temperatures.

It was impracticable to simulate in the laboratory the operation of the field grouting systems that were to be used at the project site. However, taking into consideration the large volumes of grout to be mixed and pumped and the long injection path of the grout down-hole through tubing, it was estimated that the peak temperatures of the grouts would be approximately 10 percent above the temperatures obtained in the laboratory.

### 3.3 FIELD TEMPERATURE DETERMINATIONS, STATION 1-A

During the summer of 1964, WES was requested to determine the down-hole temperatures of the air in the uncased section of the device-emplacement hole. Temperature determinations were accomplished by lowering thermistors down-hole on an interconnecting cable normally used in TV hole logging by the Sandia Corporation. The thermistor probes were constructed using Fenwal type GA51P1Z thermistors incased in copper tubing, sealed with epoxy compound EP-150, and attached to the cable. The system was calibrated directly using a temperature-controlled oil bath. The temperature of the oil bath was measured using a thermocouple and readout with a "Mini-mite" potentiometer-type indicator, accurate to  $\pm 1-1/2$  F. Readout of the current variation due to the resistance change of the thermistors was accomplished using a "Digitex" digital ammeter. The current through the thermistor was limited to less than 50 microamperes to eliminate significant self-heating. Calibration curves of microamperes versus temperature were determined and temperatures were extrapolated from this information.

The air temperatures determined at depths between 2,200 and 2,700 feet are given in the following tabulation and are shown graphically in Figure 3.3. These determinations are estimated to be accurate to  $\pm 2$  F.

Depth	Temperature
feet	F
2,200	114.9
2,300	115.8
2,400	117.5
2,500	118.6
2,600	119.8
2,700	121.2

However, these readings represent only the air temperatures down-hole and the continuous air exchanges from the bottom to the top of the hole prevented the air temperature from stabilizing at the temperature of the surrounding media. It is believed that when a measurement of the temperature of the surrounding medium is desired it can be accomplished by observing the equilibrium temperature of a highly drillable grout plug placed down-hole, when conditions and time permit.

TABLE 3.1 GROUT TEMPERATURE AND TIME DATA (HOLE WP-1)

Date	Elapsed Time	Temperature at				
		3,361-foot Depth	3,150-foot Depth	2,960-foot Depth	2,860-foot Depth	2,760-foot Depth
	hr:min	F	F	F	F	F
17 Jan 63	0:0 <sup>a</sup>	128	125	121	119	117
	0:19	123	116	115	121	117
	0:30	110	120	114	122	118
	0:40	111	116	114	121	118
	0:50	114	117	107	121	118
	1:00	117	116	108	121	118
	1:30	120	120	119	119	117
	2:30	124	123	122	120	117
	3:30	125	124	121	120	117
	4:30	126	124	121	120	117
	6:30	127	124	121	120	117
18 Jan 63	9:30	127	125	121	120	117
	10:30	127	125	121	120	117
	13:30	128	126	121	120	117
	15:30	133	129	122 <sup>b</sup>	120	117
	16:30	136	132	122	120	117
	17:30	138	135	122	120	117
	19:30	141	139 <sup>b</sup>	122	120	117
	20:30	142 <sup>b</sup>	139	122	120	117
19 Jan 63	21:30	140	138	122	120	117
	23:30	137	136	122	120	117
	26:30	134	132	122	120	117
	28:30	133	130	121	120	117
	30:30	132	129	121	120	117
20 Jan 63	33:30	131	128	121	120	117
	36:30	130	128	121	120	117
	38:30	130	127	121	120	117
20 Jan 63	42:30	129	127	121	120	117
	44:30	129	126	121	120	117
21 Jan 63	52:30	129	126	121	120	117
22 Jan 63	72:30	129	125	121	120	117
23 Jan 63	96:00	128	125	121	120	117
30 Jan 63	264:00	128	125	121	120	117

<sup>a</sup> Grout injection down-hole begun 11:30 a.m. and completed at 1:30 p.m.

<sup>b</sup> Peak temperature recorded by thermistor.

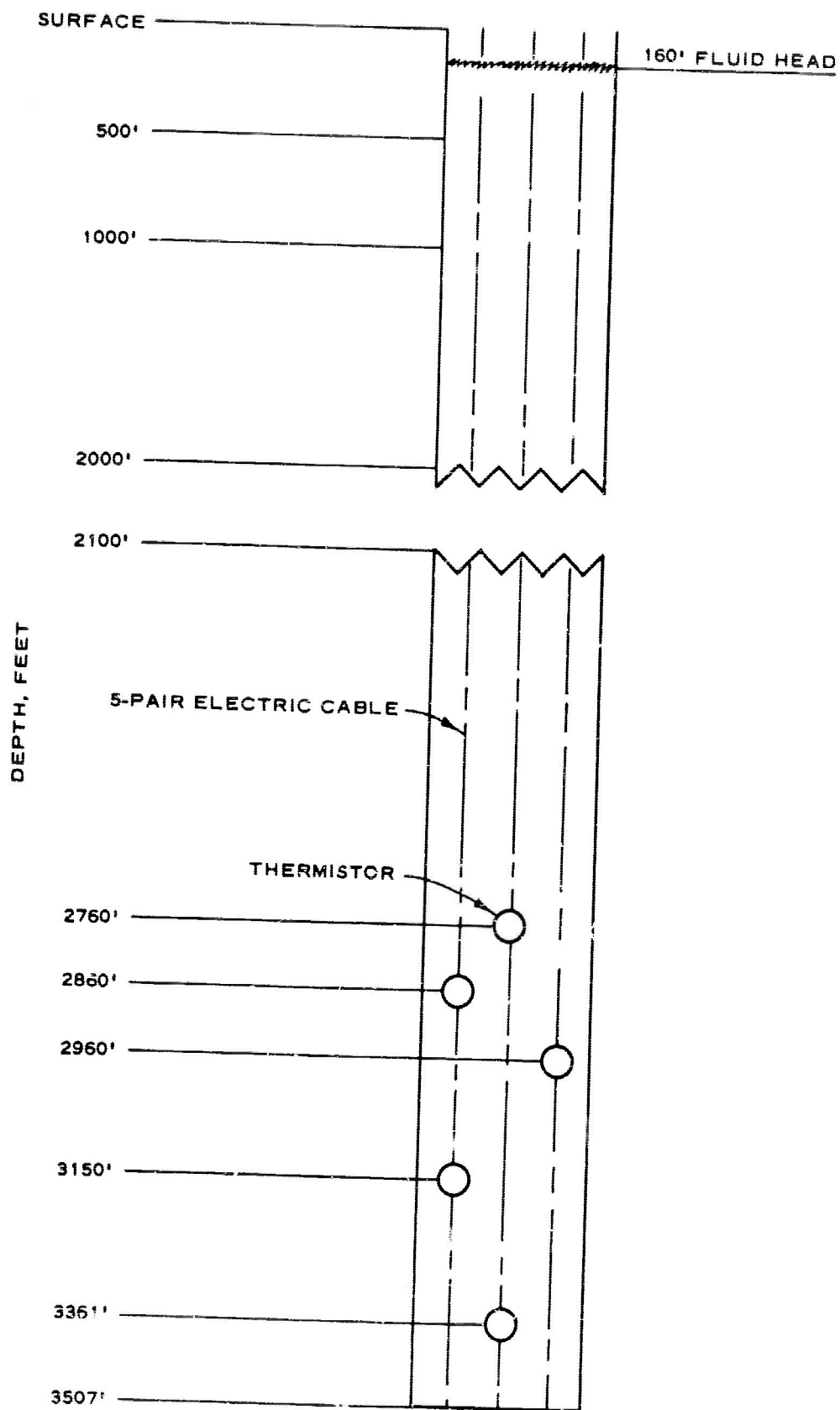


Figure 3.1 Thermistor locations (hole WP-1).

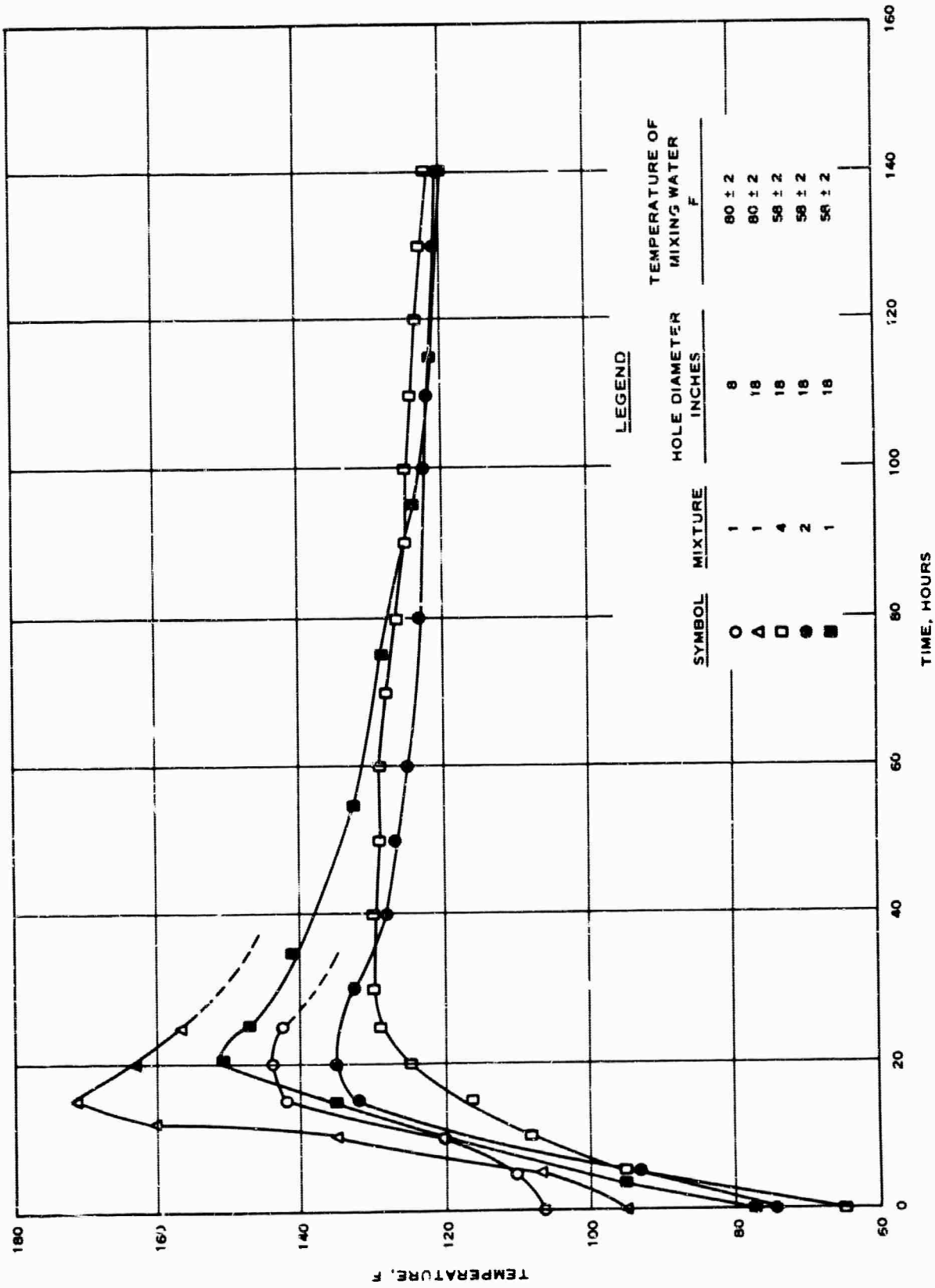


Figure 3.2 Grout temperature versus time (laboratory study).

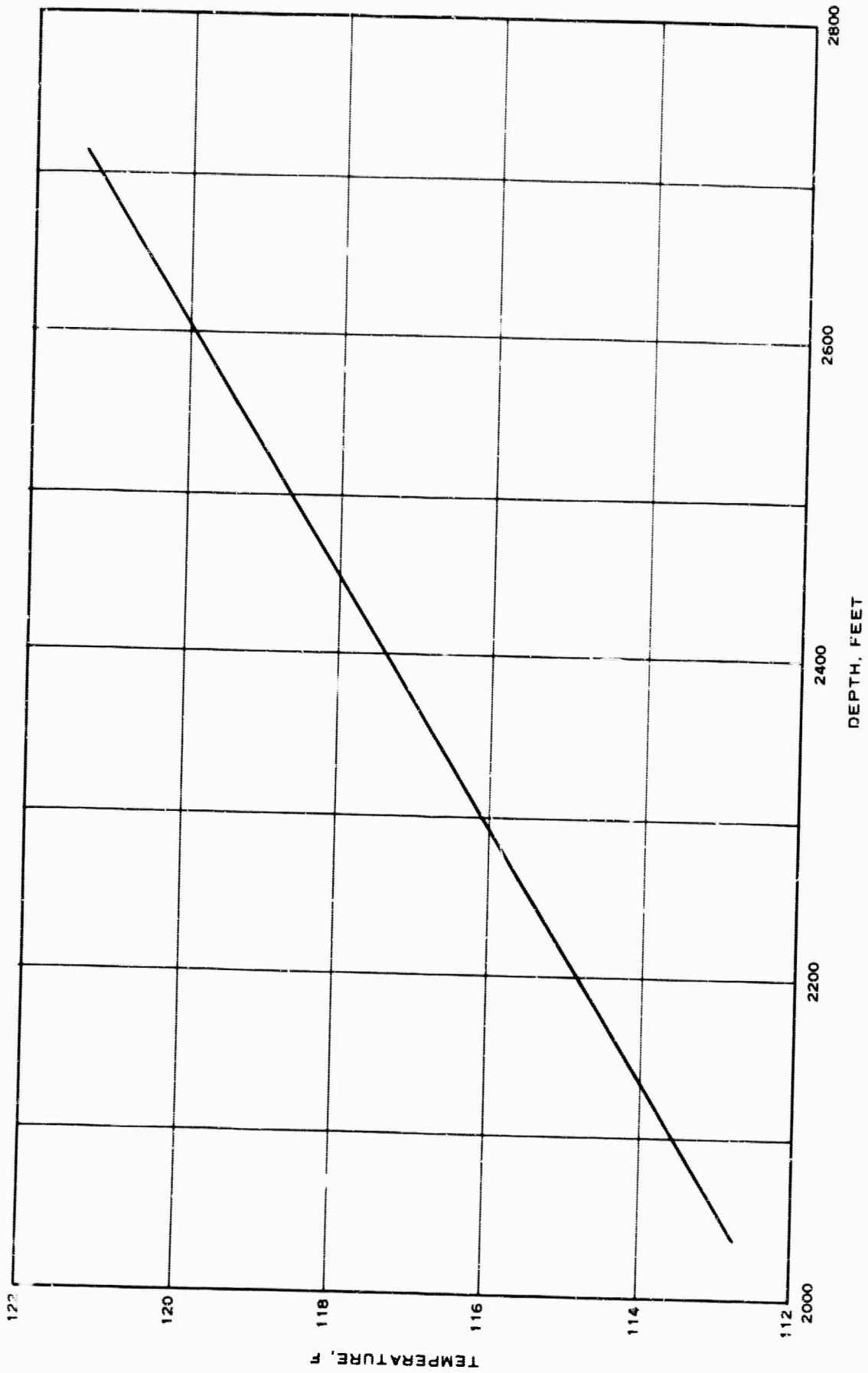


Figure 3.3 Air temperature versus depth (station 1-A).

## CHAPTER 4

### INSTRUMENTATION FOR GROUTING AND STEMMING

#### 4.1 HEIGHT-OF-GROUT DETERMINATIONS

Over the years, as a result of circulation-loss problems in grouting instrument holes and need for stage-grouting in both dry and fluid-filled, deep instrument holes, it became evident that instrumentation for determining the elevation of grout down-hole was required. Prior to Project DRIBBLE, WES conducted a laboratory investigation to develop such instrumentation. The instruments developed and successfully used in connection with various underground high-explosive and nuclear experiments are described in WES Miscellaneous Paper No. 6-650, entitled Instruments for Determining the Elevation of Grout in Deep Holes. The differential transformer (model D) and the pressure-differential switch used in the Salmon Event holes are described in Appendix A hereto.

#### 4.2 ADEQUACY OF PEA GRAVEL STEMMING, STATION 1-A

WES was asked to develop a means for monitoring the progress and adequacy of the pea gravel stemming planned for the station 1-A hole. Laboratory studies revealed that a series of microswitches could be located down-hole to accomplish this monitoring. The system consisted of enclosing a type E microswitch, produced by Micro Switch Corporation, in rectangular metal tubing with the actuating lever extended 2 inches downward and out at an angle of approximately 45 degrees (Figure 4.1). The readout console consisted of one 12-volt battery and a light corresponding to each switch. The switches were located at various depths down-hole. Figures 4.2 and 4.3 show the laboratory apparatus used to test the switches under simulated field conditions.

These switches monitored the "free-fall" passage of the pea gravel down-hole by a random, intermittent on-off indication of the monitoring readout lights. As the pea gravel gradually filled the hole, the light remained either on or off, depending on the position of the actuating lever as the gravel built up around the switch. During the actual stemming work for the station 1-A hole, one of four switches became inoperative after 12 hours of operation, probably as a result of dust built up in the switch. However, a few hours later this switch became operative again.

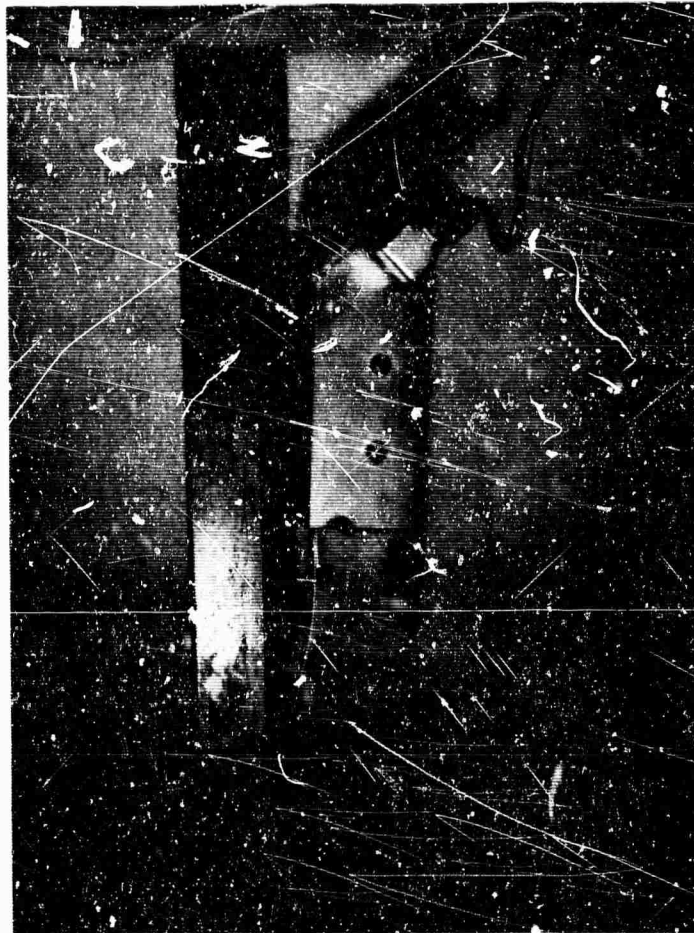


Figure 4.1 Microswitch for monitoring pea gravel placement in station 1-A stemming.



Figure 4.2 Laboratory testing of microswitches  
in 35-foot-deep, 6-inch-diameter simulated hole.



Figure 4.3 Laboratory testing of microswitches  
in 8-foot-deep transparent section.

## CHAPTER 5

### LABORATORY STUDIES OF STEMMING MATERIALS, STATION 1-A

#### 5.1 SAND-GROUT PLUGS

In connection with stemming studies for station 1-A, WES conducted a series of laboratory experiments to determine the feasibility of using alternate layers (stages) of sand and grout for stemming the hole above the device. Two plans for stemming that were initially considered by the University of California Lawrence Radiation Laboratory are shown in Figures 5.1 and 5.2. The laboratory tests consisted of placing 2-foot-thick stages of mixture 1 on top of 2-foot-thick stages of a highly free-flowing, low-bulking, specially graded Ottawa sand. These tests were performed in transparent Lucite tubing 5.75 inches in diameter and 7 feet long (Figures 5.3 and 5.4).

The tests revealed that grout "bleed-out" water emerged at the bottom of each grout stage, permeating the voids in the sand. This water appeared initially at the interface of the sand and grout stages and gradually seeped down into the sand stage. This condition resulted in a reduced volume of the grout stage immediately above the sand and in a reconsolidation of the sand stage immediately below the sand-grout interface, thus causing large voids to form in the sand in this area.

As a result of this study, this type of stemming was not recommended.

#### 5.2 PEA GRAVEL

WES was called upon to perform laboratory tests of pea gravels from five sources in Mississippi and Louisiana to determine the acceptability of the pea gravel as stemming material for the station 1-A hole. The

acceptance tests were derived from specifications based on field tests performed by the Nevada Testing Laboratory, Ltd., to determine the suitability of sand and pea gravel for use as stemming materials.

Samples of pea gravel were tested from the following sources: Lambert Sand and Gravel Company, Bayou Sara Creek, Bains, La.; Holloway Sand and Gravel Company, Cole Pit, Jackson, La.; Jahncke Services, Inc., Bluff Creek Plant, Clinton, La.; American Sand and Gravel Company, Plant D, Hattiesburg, Miss.; Traxler Brothers Gravel Company, Utica, Miss.

Based on the results of the tests, shown in Table 5.1, the pea gravel produced by Traxler Brothers was recommended. The recommended specifications for the acceptance of this material stated that the materials shall be uncrushed, rounded pea gravel having the following characteristics.

1. Sieve size: 100 percent passing 1/2-inch sieve, 95 to 100 percent passing 3/8-inch sieve, and 0 to 5 percent passing No. 20 sieve.
2. Particle shape (flat and elongated particles): 0 to 12 percent at a ratio of 1:2, 0 to 12 percent at a ratio of 1:3.
3. Specific gravity (apparent): 2.5 to 2.7.
4. Absorption: less than 3 percent.
5. Bulking factor: less than 1.5 percent.

TABLE 1.1 RESULTS OF TESTS OF PEA GRAVEL

Producer	Sieve Size	Passing	Flat and Elongated Particles		Specific Gravity SSD	Absorption	Unit Weight		Bulking
			pct	Ratio			Rodded	Dropped 10 feet	
			1:2	1:3					
Lambert Sand and Gravel Company	3/4-inch	100	--	1.2	2.55	2.2	97.6	--	--
	1/2-inch	76							
	3/8-inch	40							
	No. 4	31							
Holloway Sand and Gravel Company	3/4-inch	100	16.7	1.5	2.54	2.7	101.0	100.6	5.3
	1/2-inch	71							
	3/8-inch	62							
	No. 4	9							
Jahncke Services, Inc.	3/4-inch	100	2.6	--	2.52	3.0	99.9	--	--
	1/2-inch	98							
	3/8-inch	82							
	No. 4	17							
American Sand and Gravel Company	3/4-inch	100	16.3	1.6	2.55	1.4	102.1	101.2	3.2
	1/2-inch	89							
	3/8-inch	63							
	No. 4	4							
Traxler Brothers Gravel Company	3/4-inch	100	10.4	7.1	2.57 <sup>a</sup>	2.6	96.0	--	0.9
	1/2-inch	100							
	3/8-inch	90							
	No. 4	47							
	No. 8	12							
	No. 20	0.2							

<sup>a</sup> Apparent specific gravity.

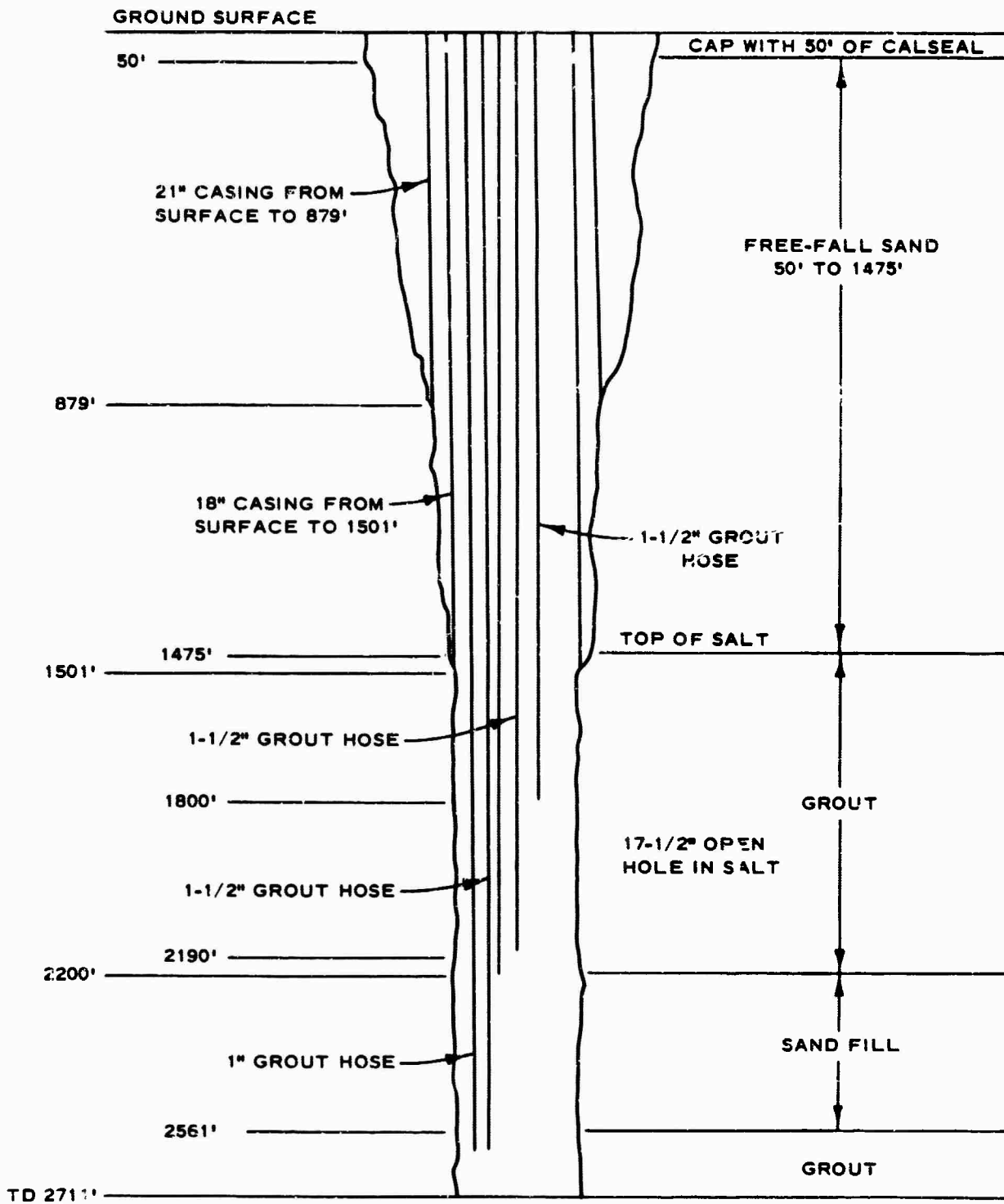


Figure 5.1 Stemming plan (alternate No. 1).

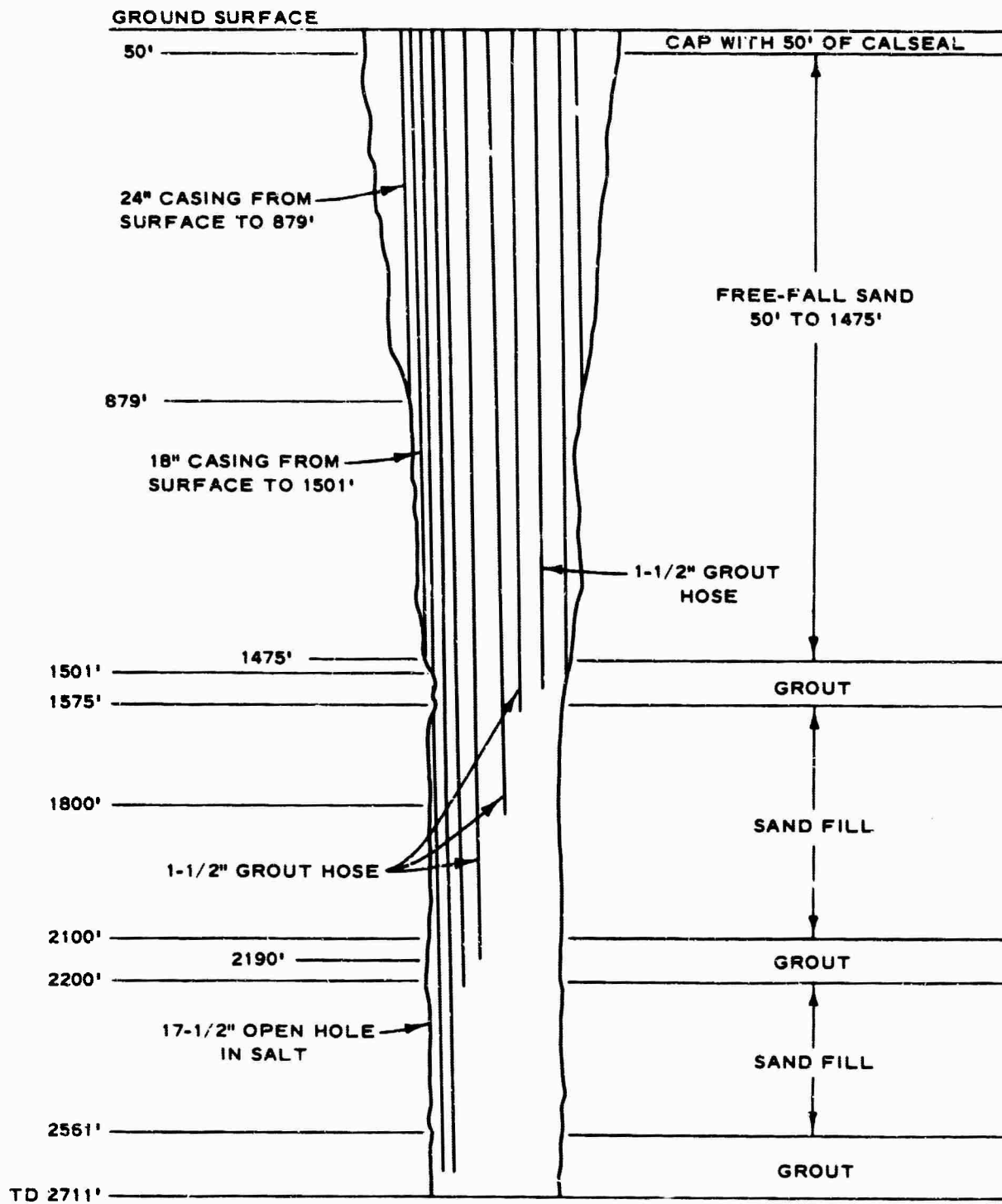


Figure 5.2 Stemming plan (alternate No. 2).

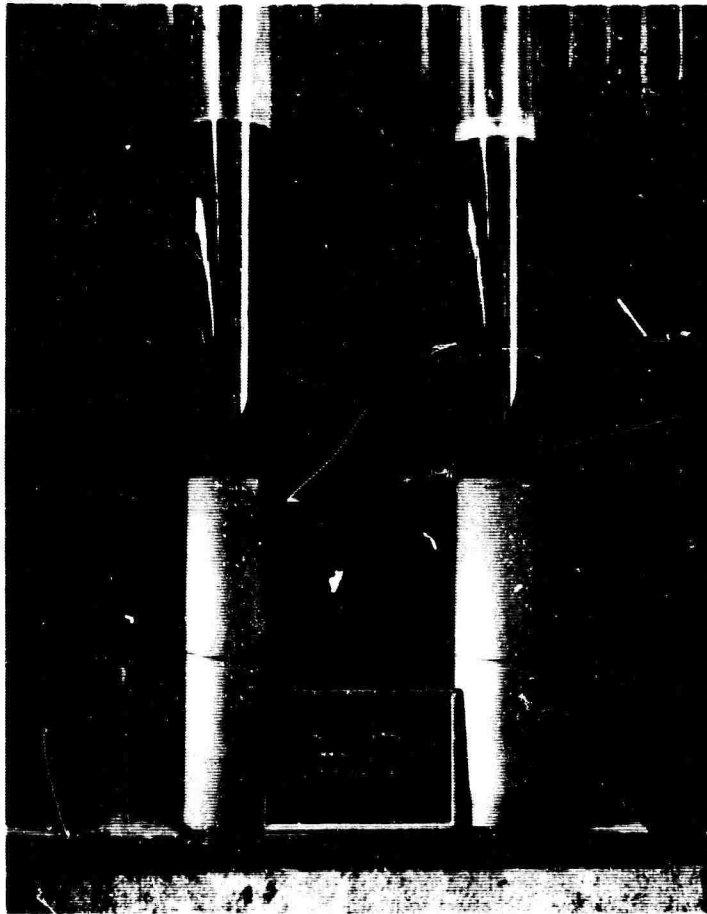


Figure 5.3 Test setup for grout-sand plug stemming studies.

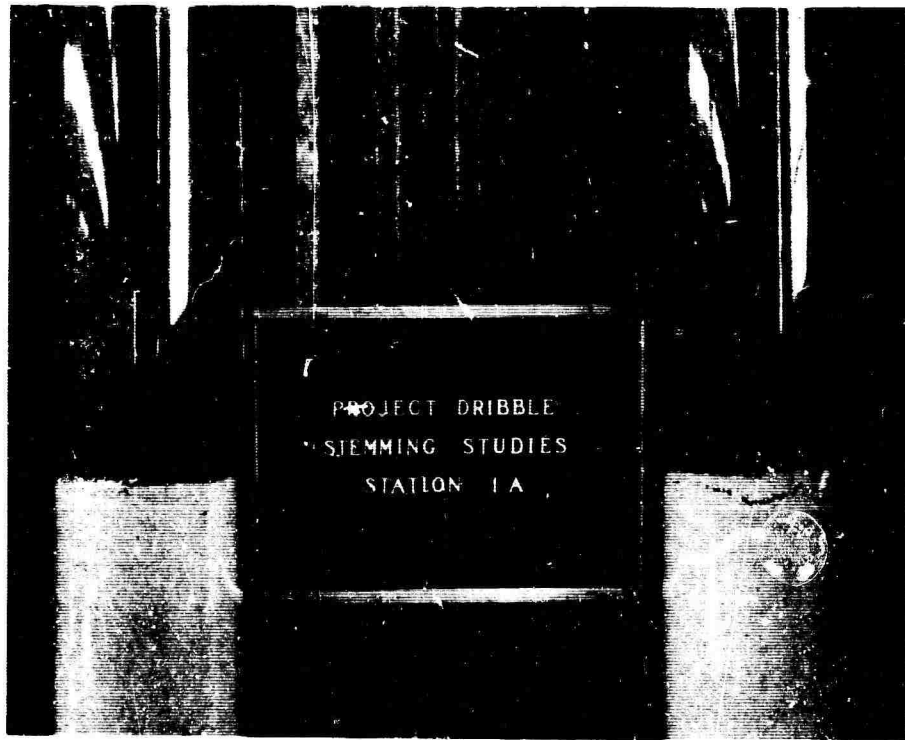


Figure 5.4 Interface of grout-sand plugs in stemming studies.

## CHAPTER 6

### MISCELLANEOUS LABORATORY STUDIES

#### 6.1 DETERMINATION OF DRILLING MUD SONIC VELOCITY

The ultrasonic pulse velocities of two 1-gallon samples (designated A and B) of drilling mud, obtained from hole E-15, were required by the hole user. To obtain this information, nineteen soniscope tests of the samples were made using the procedures described in the following paragraphs.

Three types of sample containers were used in the tests: a 6-by-12-inch cylindrical cardboard container with metal bottom (lengths shorter than 12 inches were used when appropriate); a plastic tray 10 inches wide, 12 inches long, and 5 inches deep; and a plastic bag.

For tests 1 to 8, 10, and 11 the cardboard cylinders were used with the transmitter of the soniscope<sup>1</sup> in contact with the bottom of the container and the receiver in contact with the top surface of the mud, except that in test 2 it was suspected that the receiver was touching the side of the container at the top. In test 9, the mud was placed in a plastic bag. However, the only plastic bags available were not of sufficient quality to contain the mud without danger of loss; hence, use of plastic bags was discontinued. The plastic tray was used for tests 12 to 19. In these tests, the transmitter was in contact with the bottom of the tray at its center. The receiver was in contact with the surface of the mud either directly

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<sup>1</sup>CRD-C 51-57, Method of Test for Pulse Velocity of Propagation of Elastic Waves in Concrete.

over the transmitter or moved in the lengthwise dimension of the tray, still in contact with the mud surface.

Tests 1 to 7 were conducted on 21 September 1964, and tests 8 to 12 on 22 September. For the tests, the temperature of the samples was brought to approximately 110 F, after which the pulse velocity was determined. The test conditions and results are given in Table 6.1.

After the tests on 22 September, the material in the tray (test 12) was left overnight and tested in the settled condition (tests 13 to 16) and after restirring (tests 17 to 19) the next day. The receiver was moved lengthwise 2 inches from the center of the tray for tests 15 and 18, and 4 inches for tests 16 and 19.

When the receiver was lifted from the mud surface, no signal was received through the air, thus obviating the possibility that transmission through air affected results, as had been suspected in some of the exploratory tests. The fact that no signal was received at the 4-inch displacement position also tended to rule out both transmission through air and transmission laterally through the bottom of the container.

When the limitations of the equipment (designed for transmission through 1 to 50 feet of concrete) are considered, it appears possible to conclude only that the velocity through the material tested is predominantly in the range 450 to 550 ft/sec. No conclusions can be drawn concerning the effects of the variables, i.e. contamination, settlement, and temperature. Attenuation of the sonic pulse in the material was so great that the maximum distance through the material that could be examined was about 4.5 inches. Transmission was much better at shorter distances where, however, errors caused by the geometry of the containers and transducers tended to increase.

## 6.2 DETERMINATION OF SONIC VELOCITY OF CASING CEMENTING MIXTURE

Ultrasonic pulse velocities were determined on the cement mixture used for cementing the second and third stages of the 29-inch-diameter casing at station 1-A. Four specimens, 3 inches in diameter and 15 inches long, were cast from the mixture used. The test results were as follows.

Specimen No.	Age	Ultrasonic Pulse Velocity
	days	ft/sec
1	10	8,200
2	10	7,800
3	10	8,000
4	10	8,100
	Average	8,025

On the shot date, the average velocities of the specimens were determined to be 10,600 ft/sec.

## 6.3 CABLE DEFORMATION STUDIES

An investigation of cable deformation was conducted by WES to determine to what extent, if any, instrument cables deformed and permitted leakage in hardened grout stages subjected to hydrostatic heads above the grout stage. The following four cables were tested:

Cable	Description
A	3/4-inch diameter with 27-conductor, basket-weave shielding.

(Continued)

---

Cable	Description
-------	-------------

---

- |   |  |
|---|--|
| B | 1/2-inch diameter with 50-ohm, aluminum-tube shielding and foam.           |
| C | 3/4-inch diameter with double-jacket, 7-conductor, basket-weave shielding. |
| D | 1/2-inch diameter with 50-ohm, copper-tube shielding.                      |
- 

A specimen of each cable was embedded in 6-by-12-inch grout cylinders (mixture 1). Following a curing period of from four to six days, the cylinders were sealed at the sides with a heavy rubber membrane, placed in the triaxial chamber, and sealed at the bottom with an "O" ring (Figures 6.1, 6.2, and 6.3). The triaxial chamber assembled was then positioned in a loading machine which held the piston of the chamber in place when the chamber was pressurized to various hydrostatic loadings using dyed water. The dyed water, also used to trace leakage, was injected into the chamber by means of a high-pressure pot. Figure 6.3 shows the pressure pot (smaller cylindrical chamber) and the triaxial chamber (larger chamber). Cables A and C were tested at 500-psi and B and D were tested at 1,200-psi hydrostatic pressure. Also Shore durometer hardness tests were conducted on samples of the outer insulation taken from each cable (Table 6.2). Figures 6.4 through 6.7 show the grout cylinders dissected after testing, exposing the embedded cables.

Leakage developed in both legs of the embedded cables and was confined to the interface formed between the cable surface and the surrounding grout. In Figures 6.4 to 6.7, the dark areas in the cable grooves of the dissected sections indicate the leakage path. The discoloration beside

the cable and cable grooves indicates wet areas; the remainder of the sections had dried after dissection and subsequent exposure to the laboratory ambient temperature.

The test results indicated that a problem in cable-grout interface leakage did exist. Table 6.2 shows that the cable-deformation problem is quite pronounced in cables A and C where the fluid flow was approximately 600 and 500 ml/minute, respectively, at 500-psi pressure as opposed to 0.5 and 1.0 ml/minute for cables B and D, respectively, at 1,200-psi pressure. The small amount of leakage exhibited by cables B and D is attributed to the aluminum and copper tubing shielding of these two cables which provided resistance to deforming.

A method of preventing fluid leakage, consisting of affixing to the cable two "Condulet Connectors" connected by a 4.5-inch galvanized nipple, coating the connectors and nipple with an epoxy ("Steelcote Grout No. 2"), and impregnating this coating with 20 to 40 sieve size Ottawa sand (Figure 6.8) to produce a surface texture which increased the subsurface bonding area of the connectors and nipple appreciably, was tested and proved to be successful. Fluid pressures were held for 30 minutes at 500 psi and later at 1,000 psi without fluid leakage occurring.

The following methods were also tested, but proved unsuccessful:

- (1) using epoxy joint-sealing materials for coating the cable only and for coating the connectors and nipple; and
- (2) subjecting fresh fluid grout to 500-psi pressure and allowing the grout to harden for two and seven days while still under pressure.

#### 6.4 DEVELOPMENT OF GROUT BYPASSES

Because of the limited annulus area that would exist between the walls of various drilled holes and certain instrument canisters to be lowered into these holes, WES was called upon to develop grout bypasses for "in-line" attachment to the 1-inch-ID plastic hoses to permit pumping the grout by and below the canisters emplaced down-hole.

The bypass sections were to be 27 feet in length, and were to be designed with transitions immediately above and below the canister to provide for coupling to the 1-inch-ID plastic hoses. Following preliminary studies, the configuration shown in Figures 6.9 and 6.10 was decided upon. Figure 6.11 shows a top view of the relative position of the grout bypass when attached to the section of a canister which will when emplaced down-hole be the most restricted area.

Two sections conforming to the configuration shown in the figures were molded at the WES of fiber glass. Two additional sections were later fabricated from aluminum sheet metal. A specification requirement was that the bypass be able to withstand a hydrostatic pressure of 150 psi for one hour. During laboratory testing, both the fiber-glass and aluminum sections failed at approximately 100 psi. Because of their concave design, the sections tended to "round out" during pressurizing and rupture at the edges. This rupturing was considerably more pronounced in the fiber-glass sections. Subsequent tests of the aluminum bypass, reinforced down the center with a stiffener, proved successful.

TABLE 6.1 ULTRASONIC PULSE VELOCITIES OF DRILLING MUD SAMPLES

Date	Sample	Test No.	Type of Sample Container	Length of Pulse Path	Temperature	Velocity	Test Condition
Sept 1964				inches	F	ft/sec	
21	A	1	Cylinder	5.50	112	No signal	Sample freshly stirred.
	A	2	Cylinder	4.50	112	1,135	Sample freshly stirred. Receiver touching container.
	A	3	Cylinder	3.60	112	405	Sample freshly stirred.
	A	4	Cylinder	3.00	112	575	Sample freshly stirred.
	A	5	Cylinder	2.00	112	570	Sample freshly stirred.
	A	6	Cylinder	2.00	112	515	Sample freshly stirred.
	A	7	Cylinder	2.50	108	555	Sample freshly stirred.
22	A	8	Cylinder	3.25	110	490	Sample freshly stirred.
	A	9	Bag	5.50	110	545	Sample freshly stirred. Tested in plastic bag.
	B	10	Cylinder	3.50	110	495	Sample freshly stirred.
	B	11	Cylinder	3.50	110	505	Same as test No. 10 except undisturbed for five hours.
23	A	12	Tray	2.00	110	435	Plastic tray. Sample freshly stirred.
	A	13	Tray	2.00	110	470	Settled overnight.
	A	14	Tray	2.00	108	465	Settled overnight.
	A	15	Tray	2.83 <sup>a</sup>	108	555	Settled overnight.
	A	16	Tray	4.50 <sup>a</sup>	108	No signal	Settled overnight.
	A	17	Tray	5.08	107	630	Restirred.
	A	18	Tray	2.83 <sup>a</sup>	107	465	Restirred.
	A	19	Tray	4.50	107	No signal	Restirred.

<sup>a</sup> Diagonal path; length calculated.

TABLE 6.2 CABLE DEFORMATION TESTS

Cable	Shore Hardness <sup>a</sup>	Total Compression	Bond Area of Both Cable Legs	Bonded Area	Leakage Around Cable
		psi	inches <sup>2</sup>	psi	ml/minute
A	97	500	8.68	9.0	600 (approximately)
B	89	1,200	2.94	63.0	0.5
C	93	500	8.68	9.0	500 (approximately)
D	58	1,200	2.94	63.0	1.0

<sup>a</sup> One 1-by-3-inch strip of cable insulation was removed from each cable tested for use in the Shore durometer determinations.

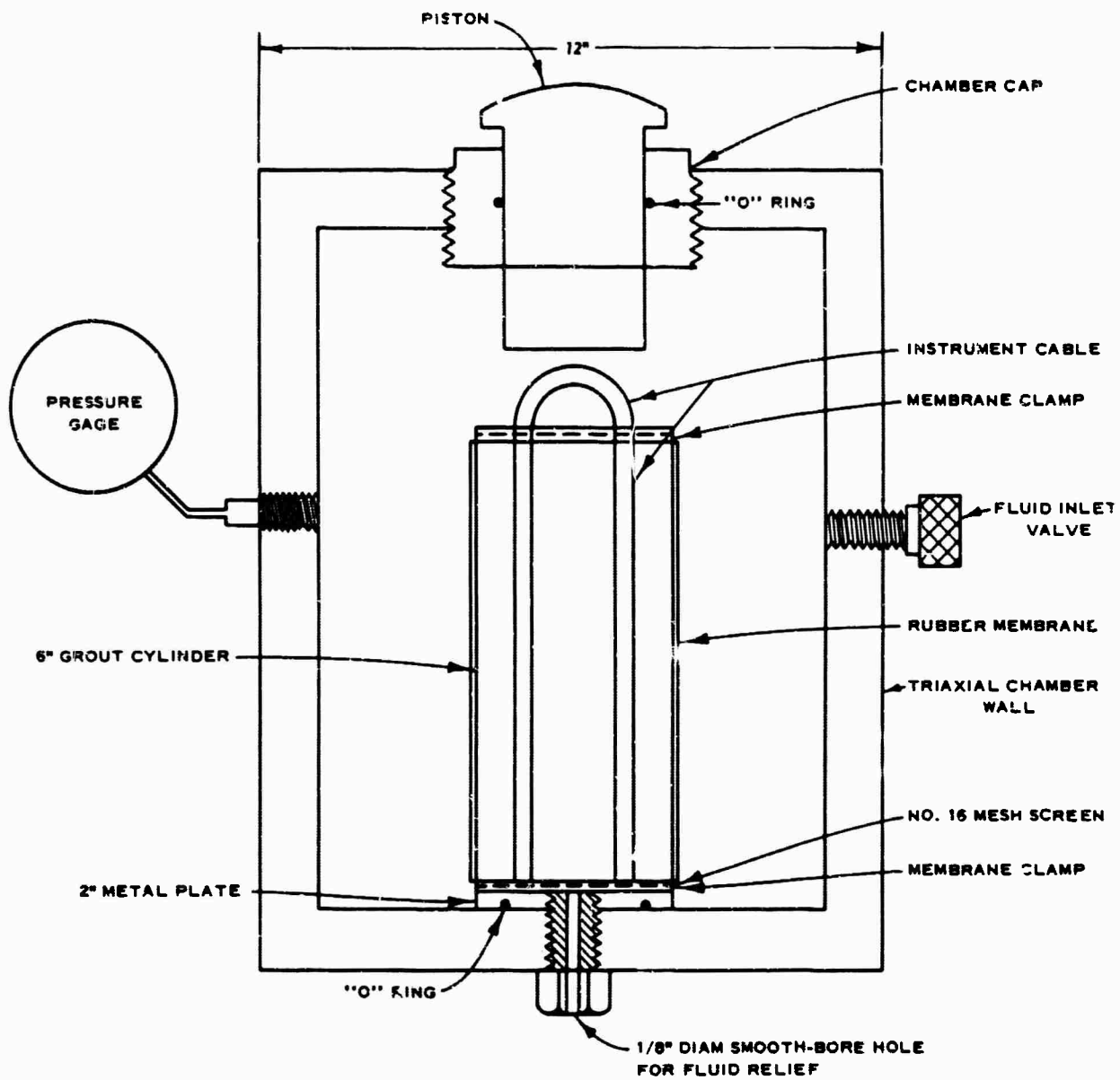


Figure 6.1 Triaxial apparatus used in testing for leakage around cable.

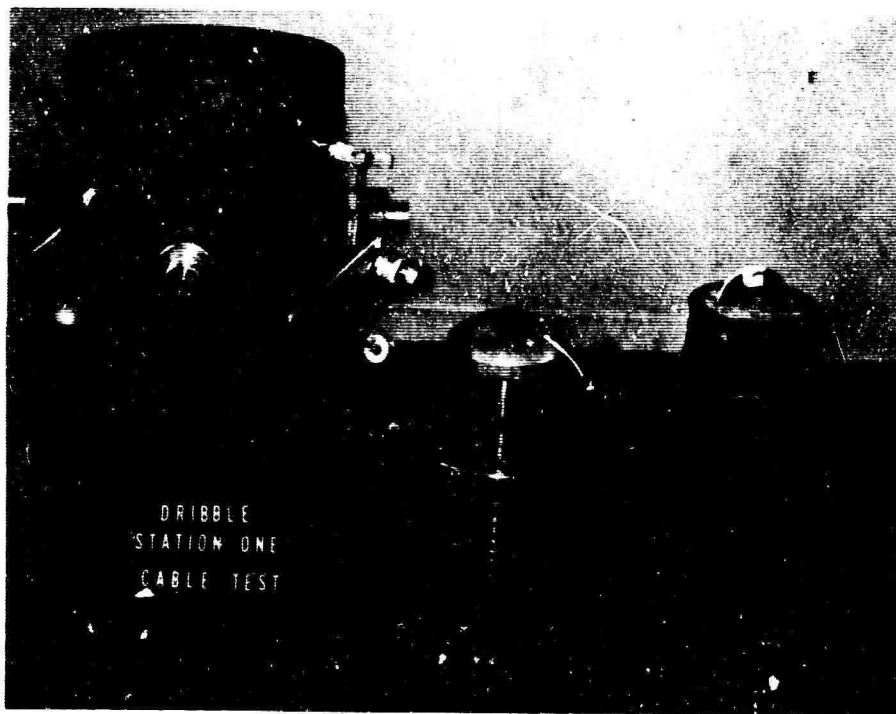


Figure 6.2 Triaxial chamber and test specimen ready for assembly.

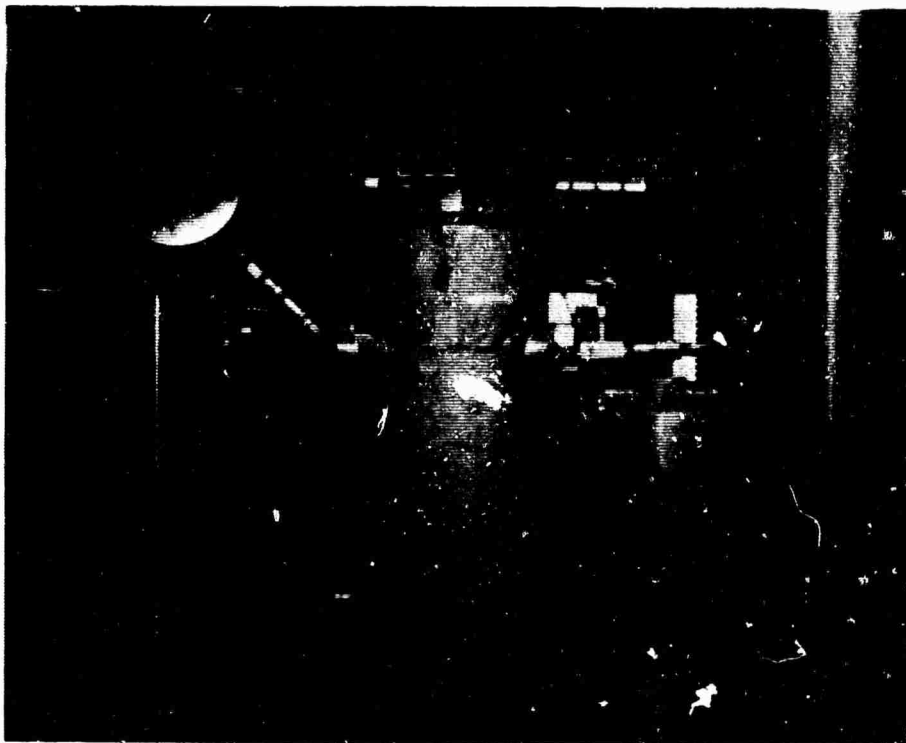


Figure 6.3 Triaxial chamber and pressure pot assembled and in testing position.



Figure 6.4 Dissected specimen showing cable A.

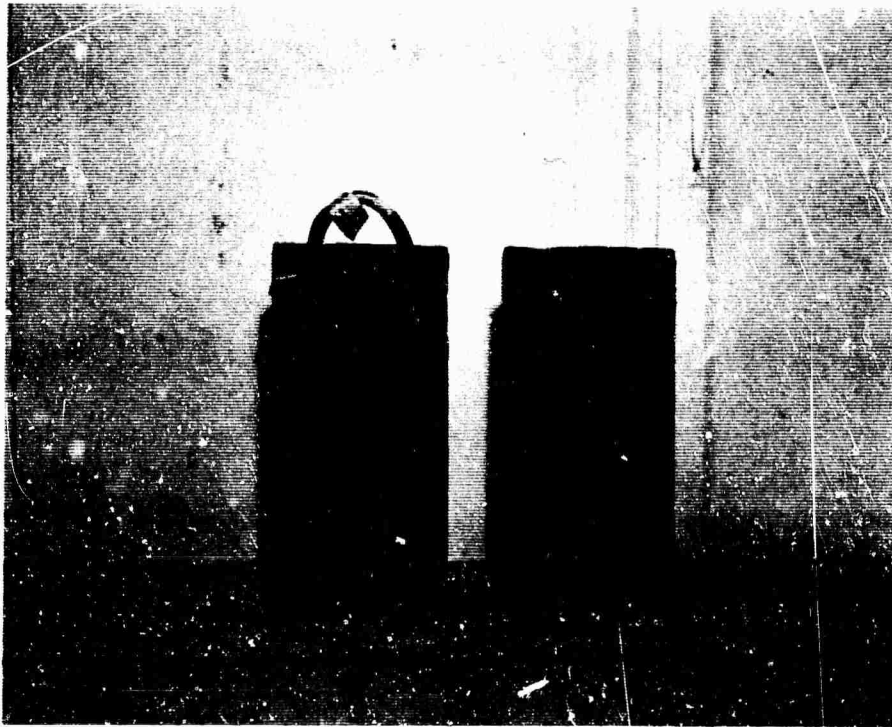


Figure 6.5 Dissected specimen showing cable B.

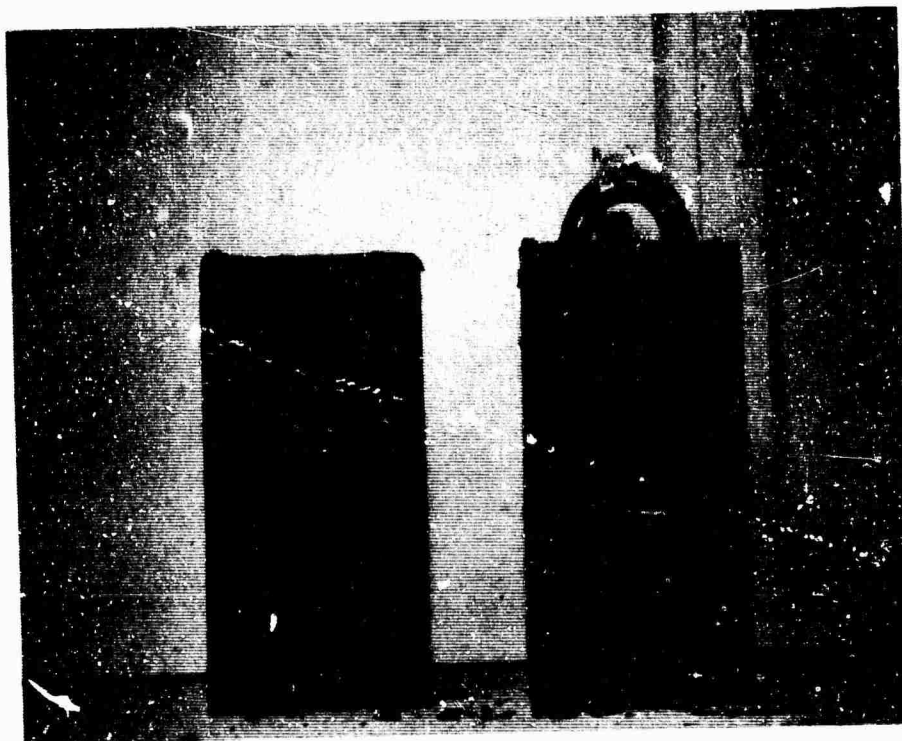


Figure 6.6 Dissected specimen showing cable C.

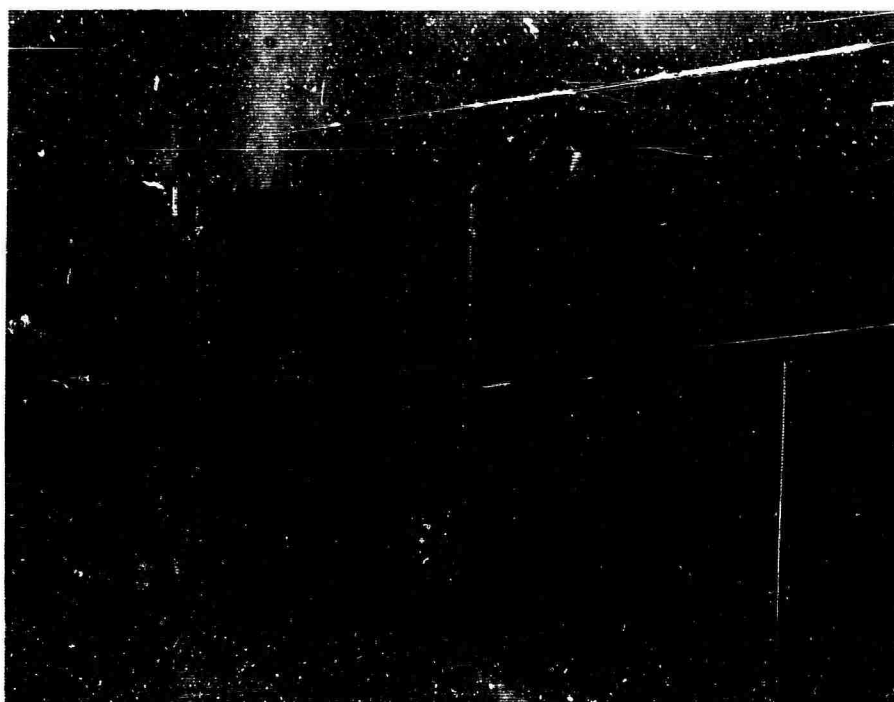


Figure 6.7 Dissected specimen showing cable D.

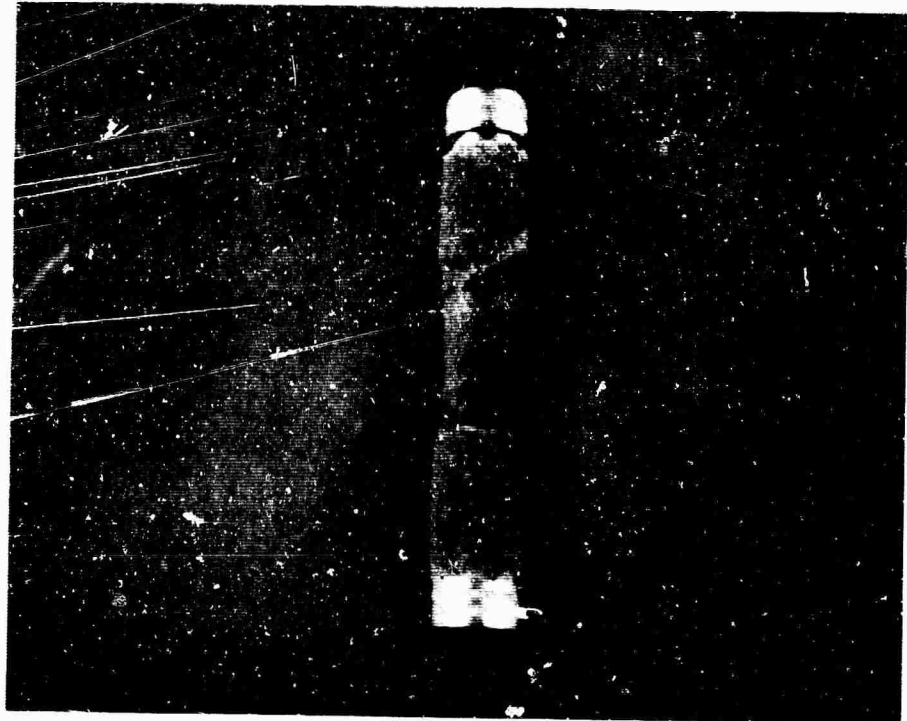


Figure 6.8 Two connectors on cable covered with epoxy and Ottawa sand coating.

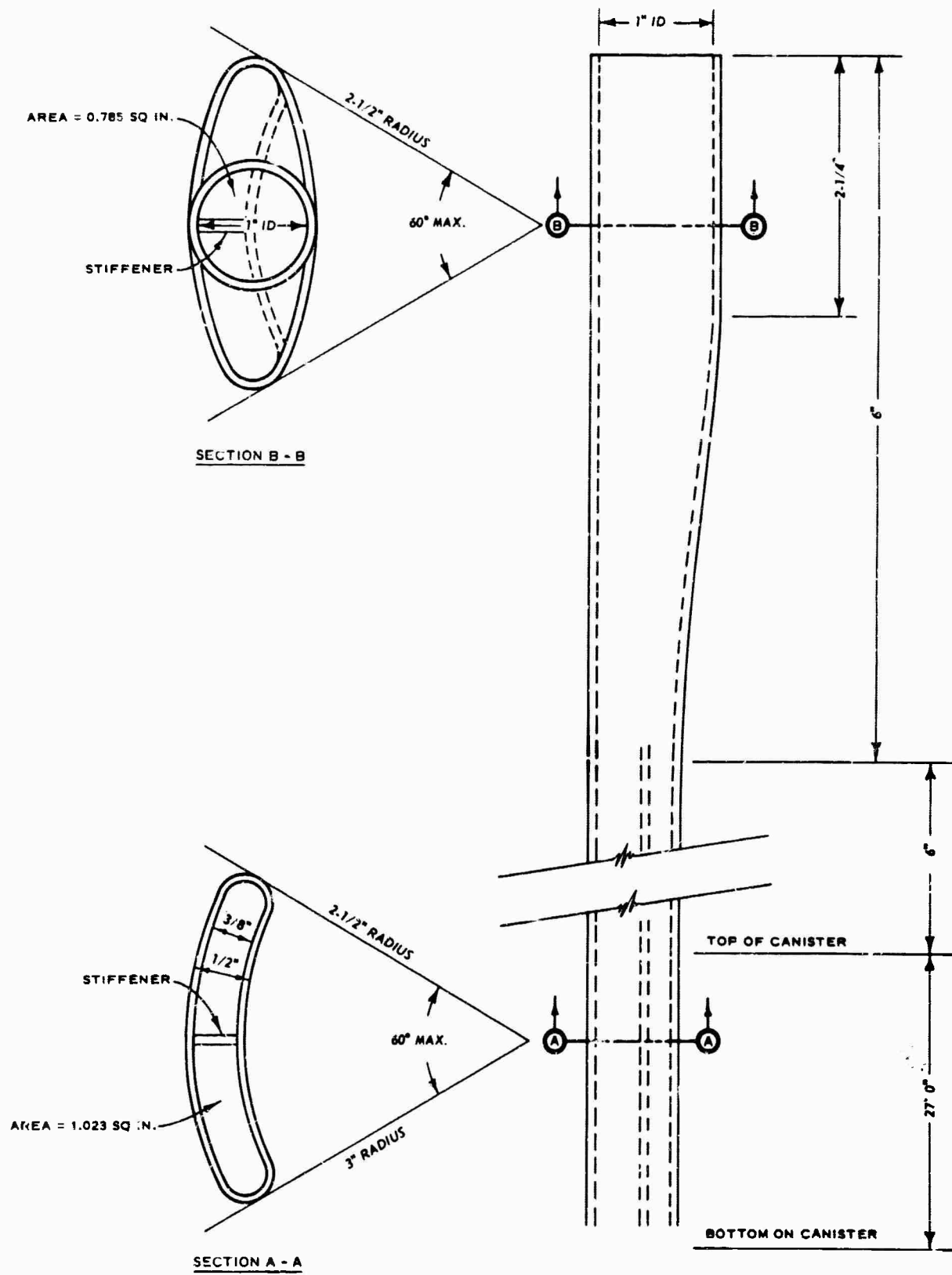


Figure 6.9 Aluminum grout bypass (side view).

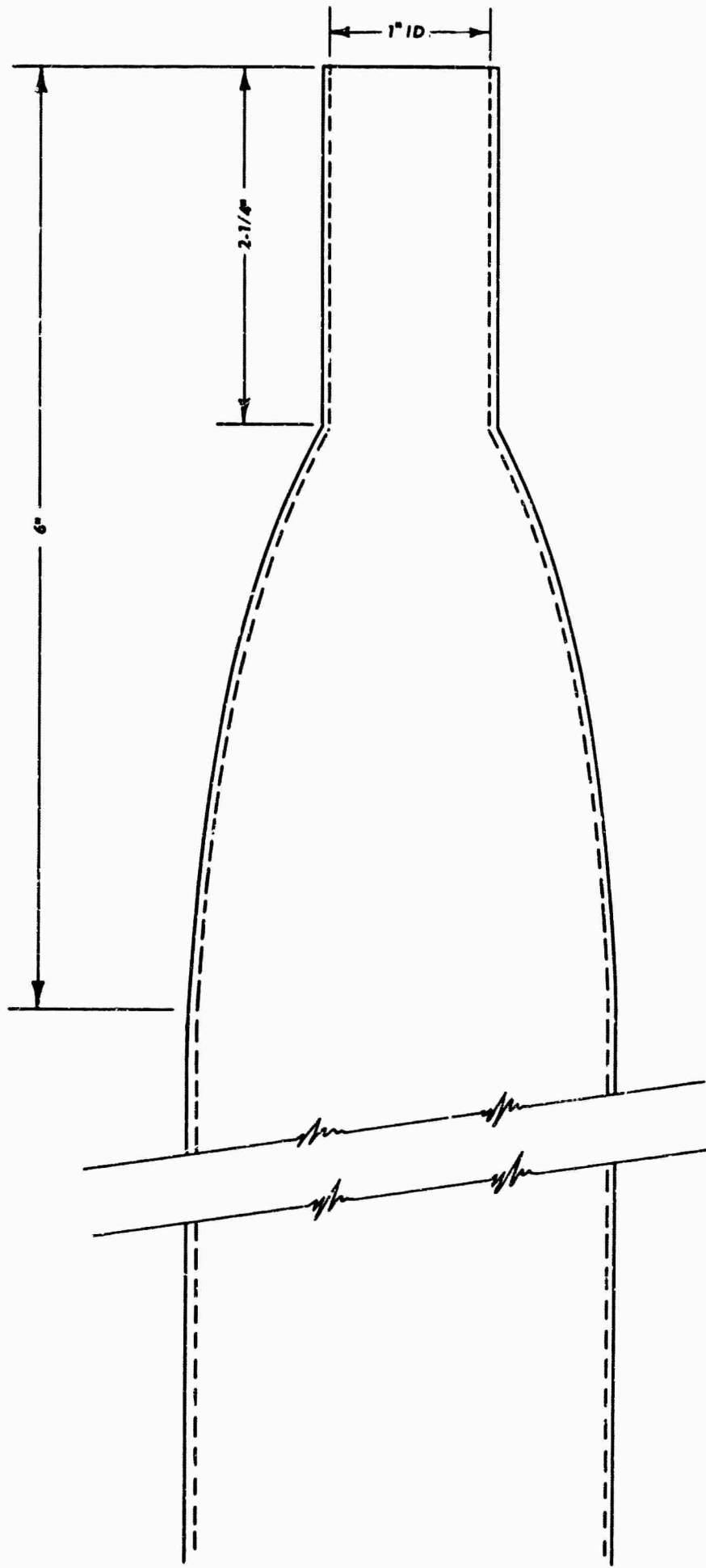


Figure 6.10 Aluminum grout bypass (plan).

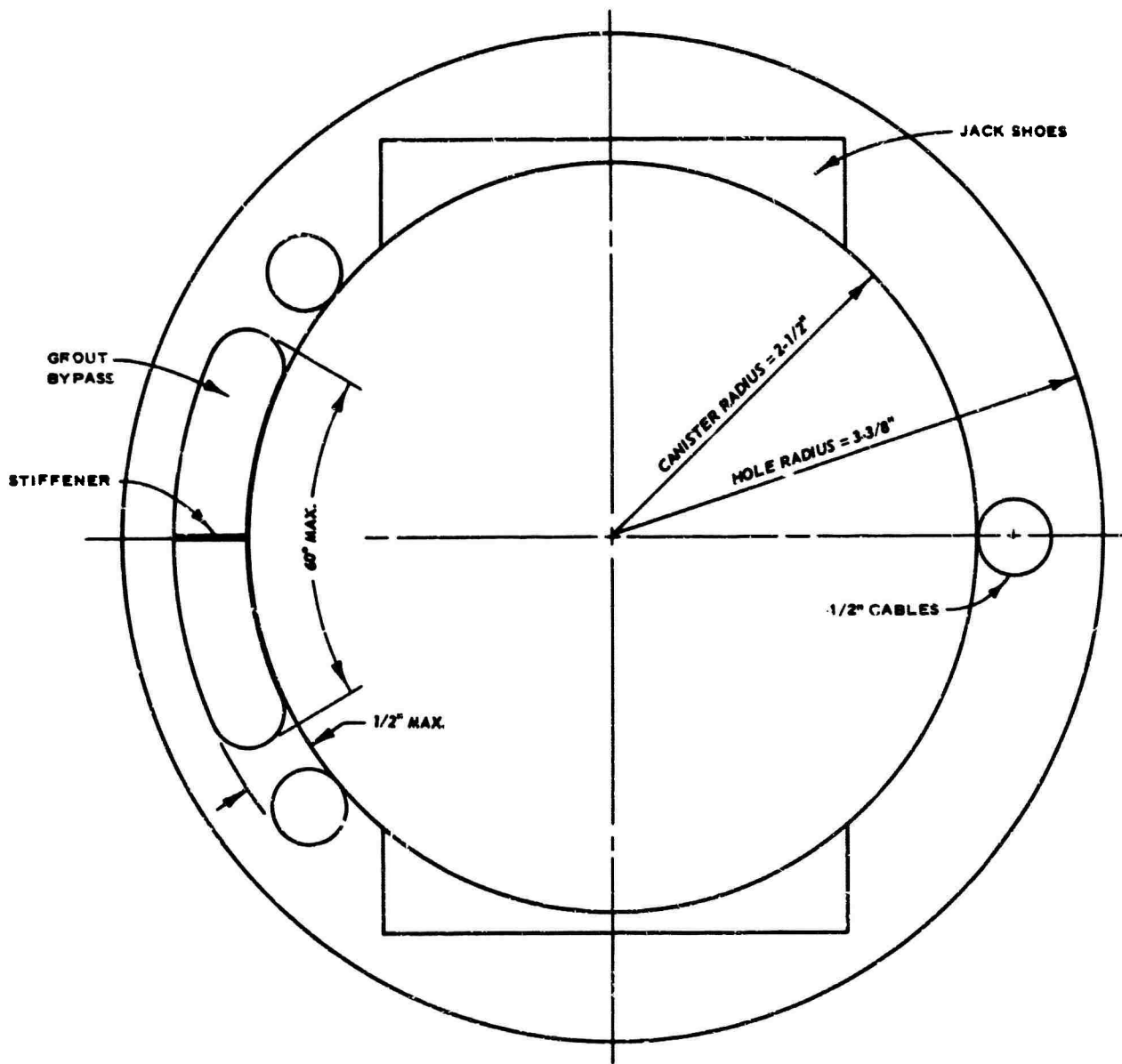


Figure 6.11 Location of grout bypass at tightest section.

## CHAPTER 7

### FIELD GROUTING

#### 7.1 FIELD GROUTING SYSTEMS

The Dowell Company and the Halliburton Oil Well Cementing Company performed the grouting of the instrument holes. In addition, the Dowell Company placed the 600-foot grout plug in the bottom of the device hole. WES personnel provided technical direction and assistance in the field for this work.

The Halliburton Company utilized twin T-10 cementing units, jet mixers, agitators, dry materials pneumatic tanks, and large-volume water tanks in the field grouting work (Figure 7.1). The Dowell Company employed DC-8 cementers, paddle mixers, dry materials pneumatic tanks, and large-volume water tanks to perform their portion of the grouting operation (Figure 7.2).

Plastic hoses, 1-inch ID, were used to place grout in hole WP-1 (temperature studies) and hole E-5. Following difficulties in instrumenting and in attempts to grout hole E-14 using plastic hoses, it was decided to perform all subsequent hole grouting employing steel tubing; with some minor difficulties, this tubing proved successful.

A field evaluation of the grouting systems of both the Dowell and Halliburton Companies was conducted to determine means of improving the quality control of the instrument grout during grouting operations. The evaluations indicated that supplementing the jet mixers and the paddle mixers with agitator-type mixing tanks provided better quality control and also provided a "backup" volume of grout for maintaining continuous pumping operations down-hole.

Both grouting systems included means to determine the density of grouts being mixed, grouting pressures, and continuous measurement of the volume of grout pumped down-hole.

## 7.2 INSTRUMENT HOLE GROUTING

An array of instrument holes, ranging from 76 to 2,436 feet in radial distance from SGZ and from approximately 891 to 4,000 feet in depth, was grouted by either the Dowell or Halliburton Companies. Figure 7.3 shows the geology of the Tatum Salt Dome. The 12 instrument holes that were instrumented and grouted are shown in plan in Figure 7.4 and in sections in Figures 7.5 and 7.6. The latter figures show the configuration of the holes, i.e. diameter and depth, the casing schedule, radial distances from SGZ, and the grouting performed for each. Figures 7.7 and 7.8 show the type and location of the instrumentation grouted in place. Instrument holes were stage-grouted by either fluid or hardened staging. Fluid staging involved pumping a few hundred feet of deep-stage grout down-hole, followed by additional stages of similar sizes pumped prior to the hardening of the previous stage. Hardened stages involved pumping a few hundred feet of deep-stage grout and waiting until each stage hardened before pumping subsequent stages of similar sizes. All stages were preceded and followed by a small volume of butter grout to provide lubrication for the grouting systems, and to prevent segregation of the sand contained in the instrument grout by acting as a spacer between the instrument grout and less viscous fluid present in the hole.

Immediately prior to the attempted grouting of hole E-14, one of five instruments being lowered down-hole became inoperative. Attempts to

withdraw the 4,000-foot instrument and grout-hose string which had been lowered 4,000 feet proved unsuccessful. It was decided to grout the four remaining operative instruments in place. Grout injection was begun through the hose which terminated at approximately 4,000 feet near the bottom of the hole. Following the injection of approximately 40 barrels of mixture 1 grout, returns were observed at the collar of the hole; this indicated that, based on the volume of grout injected, the grout hose had ruptured in the vicinity of the 1,700-foot depth. No immediate means were available to displace the grout before it reached an initial set which would prevent its displacement up-hole. Later, two holes (E-14B and E-14T) were put into the open-hole portion of E-14 using the whipstock method below the 1,700-foot depth; E-14T was put in at approximately the 1,950-foot depth, and E-14B at approximately the 3,950-foot depth. Attempts to circulate grout from E-14B, through E-14, and discharge it out of E-14T to the surface were unsuccessful, and cross-channelization is judged to have occurred between E-14B and E-14T near the 2,000-foot depth. No further remedial action was taken to grout the open-hole section of hole E-14. A new hole (E-14C) was later drilled, and successfully instrumented and grouted.

The Dowell Company grouted holes WP-1 (temperature studies), E-15, E-16, E-14C, E-14B, and station 1-A; the Halliburton Company grouted holes E-5, E-6, E-13, E-12, E-11, WP-4, WP-1, E-14, and attempted remedial action for E-14 (E-14T and E-14B). A grout bypass (see Section 6.4) was successfully used in the instrument grouting of hole E-5. However, caliper logs of the remaining instrument holes revealed that overdrilling and erosion had taken place during drilling, enlarging the diameters of the holes

enough to accomodate both instrument canisters and grouting tube down-hole, thus eliminating the need for bypasses.

### 7.3 STATION 1-A STEMMING

The principal requirements for stemming the station 1-A device hole to prevent venting were:

1. Pump a salt formation-matching grout plug down around the emplaced device and up-hole 600 feet above the device.
2. Proportion the grout mixture (mixture 2) with admixtures that would depress the cement heat-of-hydration temperature below a given temperature tolerable by the device (temperature of salt at 2,700-foot depth = 121 F).
3. Stem remainder of hole from 2,100 feet to surface with a specially graded pea gravel having a low bulking factor and a specified specific gravity and particle shape.
4. Provide down-hole instrumentation for monitoring temperature of grout during hardening and for determining the progress and adequacy of the grouting and pea gravel stemming operation.

The device was attached to the bottom of a 5.5-inch-diameter J-55 ST and C emplacement casing, and the draw works of a large drill rig were used to lower the device with associated instrumentation to the bottom of the station 1-A hole. A special 10-foot-long section of the casing was perforated with six 4-by-6-inch grouting injection ports, three each on opposite sides and spaced on 12-inch centers, located immediately above the device. The bottom of this special section was equipped with a coupling for attaching the device to the casing string for emplacement. Series of

4-by-6-inch ports were also located every 90 feet from approximately the 2,000-foot depth to the surface for internal filling of the casing with pea gravel from the 2,100-foot depth (top of grout) to the surface. During the lowering of the device, height-of-grout detectors and thermistors for monitoring the temperature of the grout were also lowered. The height-of-grout detectors were located at 2,650-, 2,485-, and 2,100-foot depths. The thermistors were located 83, 215, and 585 feet from the bottom of the hole. The microswitches were placed at 500, 1,000, 1,500, and 2,000 feet from the surface for monitoring the pea gravel stemming operation.

The first grout stage of mixture 2 was mixed and pumped down-hole through 2.37-inch-diameter Hydrill CS tubing positioned in the center of the 5.5-inch casing and sealed off at the bottom of the casing immediately above the grouting ports. The grout was mixed and pumped continuously at a rate of approximately  $1/2 \text{ yd}^3/\text{minute}$  until the grout head rose to approximately the 2,100-foot depth, which was 100 feet above the bottom of a 20-inch-OD casing (see Figure 7.9). A second stage was shortly pumped behind the first stage to fill the 5.5-inch casing to the same elevation as the first stage by allowing both stages to equalize down-hole. Stages were placed using standard displacement plugs to insure complete displacement of grout down Hydrill tubing. The second stage,  $78 \text{ ft}^3$  was placed above the first stage displacement plug which was locked into the sealer receptacle. To place the second stage, the 2.37-inch tubing was raised about 24 inches out of the sealer receptacle and the stage was pumped and displaced by a second plug for filling the 5.5-inch casing.

On the following day, the discharging of an estimated  $4,050 \text{ ft}^3$  of pea gravel, dried to a "bone dry" condition, was begun down-hole at a discharge

rate of between 200 and 300 lb/minute. The pea gravel was dried in a Barber Greene dual drum drier located at the asphalt plant of the WES approximately 125 miles northwest of the project site. At the project site, an end-loader was used to charge a 1-yd<sup>3</sup>-capacity hopper equipped with a regulating vibrator feeder which fed the pea gravel onto a 20-foot conveyor belt, which in turn discharged the pea gravel down-hole. Approximately 48 hours was required, including delays, to place the pea gravel. Figure 7.9 shows the grout and pea gravel stemming areas.

#### 7.4 TEMPERATURE DETERMINATIONS, STATION 1-A GROUT PLUG

The three thermistor probes to be placed in station 1-A hole were calibrated in the laboratory prior to use. An oil bath ranging in temperature from 90 to 200 F in 2 F increments was used in the calibration. Temperature measurements were made utilizing a thermocouple and potentiometer. The thermistors, having a negative temperature coefficient when placed in a series circuit with a battery, caused the current existing in the circuit to vary directly with the temperature of the thermistor, thereby permitting a correlation of current versus temperature to be established for the calibration. The current was monitored using a digital ammeter. Calibrations were estimated to be accurate to 1.5 F.

The three thermistor probes (illustrated in Figures 7.10 and 7.11) were placed at elevations 83, 215, and 585 feet above the bottom of station 1-A hole. All three probes were monitored for a period of 48 hours following grout placement; in addition, at the request of the device engineer, probe 1 was monitored for 17 days. This probe was located where the diameter of hole was the largest (21.5 inches), as shown in Figure 7.12.

Figure 7.13 shows the maximum temperature rise (160 F) of the grout recorded by probe 1; the final temperature recorded by this probe at the end of 17 days was 123.5 F. Probes 2 and 3 recorded maximum temperatures of 154 and 149 F, respectively.

#### 7.5 RESULTS OF TESTS ON GROUT SPECIMENS ON SHOT DATE

The results of physical tests on 3-inch-diameter grout specimens tested on device detonation date are shown in Table 7.1.

TABLE 7.3. RESULTS OF PHYSICAL TESTS ON GROUT SPECIMENS ON SHOT DATE

Hole No.	Stage No.	Depth		Unit Weight <sup>a</sup>	Ultrasonic Pulse Velocity <sup>b</sup>	Compressive Strength <sup>a</sup>
		From	To			
		feet		pcf	ft/sec	psi
WP-1	1	3,509.8	2,761.1	134.2	12,400	3,870
WP-4	1	3,506.8	2,049.8	134.2	12,475	4,200
E-4	1	2,759.8	Surface	133.7	12,345	2,570
E-5	1	2,765.1	2,100.0	133.3	12,400	4,100
E-6	1	2,750.0	1,900.0	132.5	12,475	3,760
E-11	1	3,539.0	1,799.8	125.7	11,420	3,510
E-12	1	2,881.9	2,685.0	138.1	13,585	3,680
E-14B	(Standby hole which was grouted but not instrumented)					
E-14C	1	3,950.1	3,755.9	130.0	11,960	3,400
E-14C	2	3,755.9	3,525.9	128.5	12,100	2,700
E-14C	3	3,525.9	3,071.8	129.5	11,640	3,760
E-14C	4	3,071.8	2,595.1	131.0	11,865	4,150
E-14C	5	2,091.8	995.1	129.8	12,225	3,450
E-15	1	2,533.4	2,520.0	133.7	12,475	3,220
E-15	2	2,520.0	1,725.0	128.5	11,640	3,390
E-15	3	1,725.0	1,200.1	129.6	11,755	3,300
E-16	1	970.1	500.0	94.0	7,785	1,520
E-16	2	500.0	Surface	91.6	7,595	1,390
STA 1-A	1	2,720.1	2,100.0	131.3	11,114	2,275

<sup>a</sup> Determined on 3-by-6-inch-diameter specimen.

<sup>b</sup> Determined on 3-by-15-inch-diameter specimen.



Figure 7.1 Halliburton Company grouting equipment.

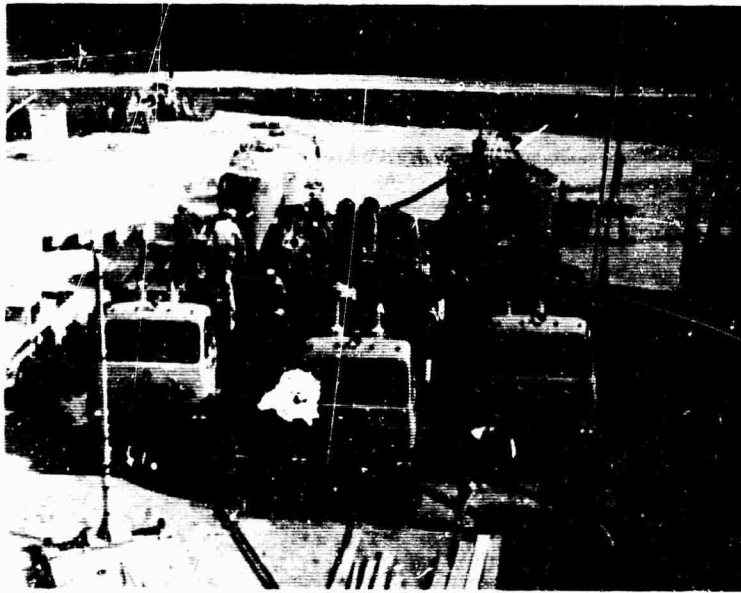


Figure 7.2 Dowell Company grouting equipment.

U. S. DEPARTMENT  
OF THE INTERIOR  
GEOLOGICAL SURVEY

SW  
A

U.S.A.E.C.  
HT-2

WILLMUT GAS & OIL CO. FREEPORT SULPHUR CO.  
NO. 3 TATUM NO. 2 TATUM

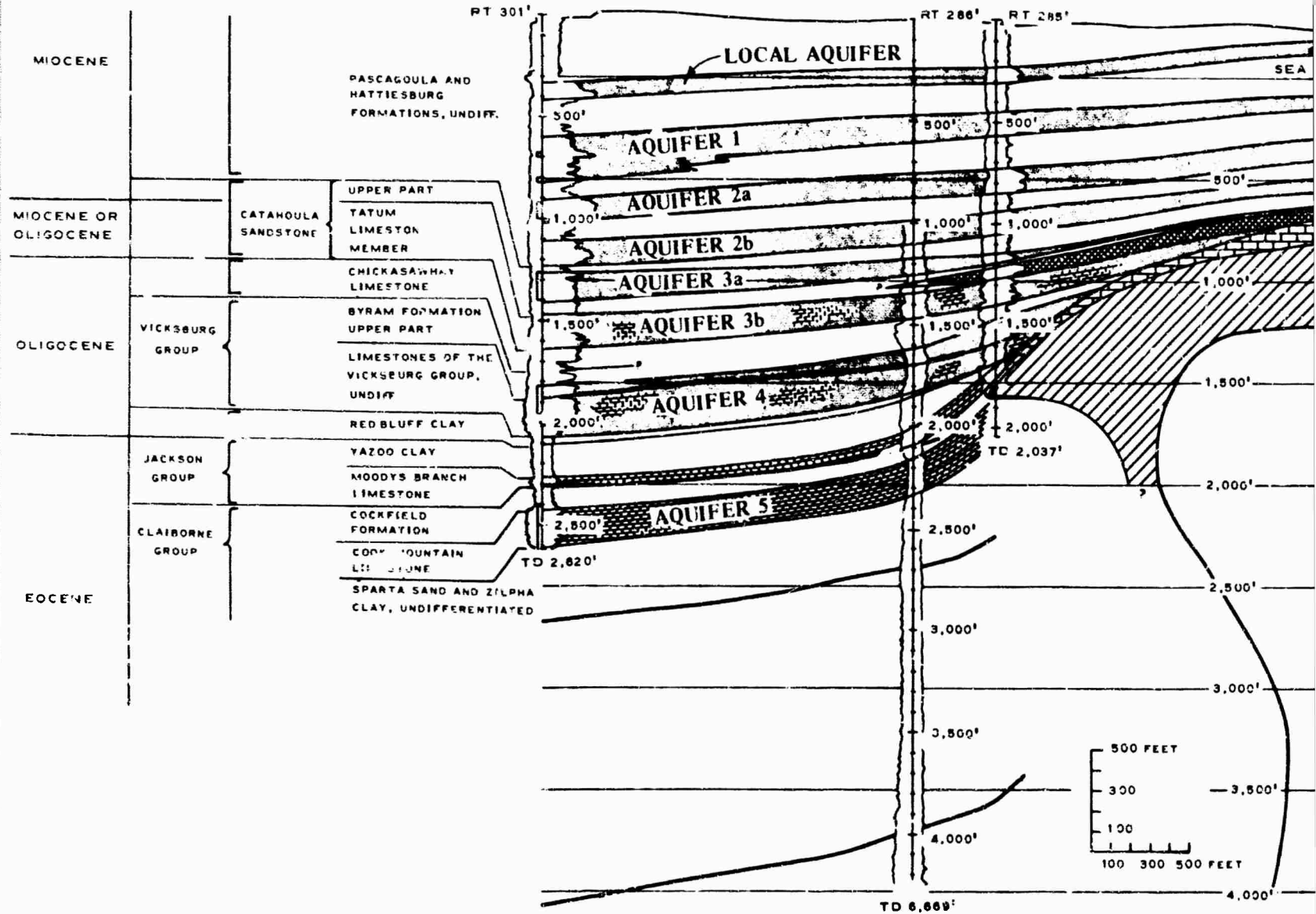
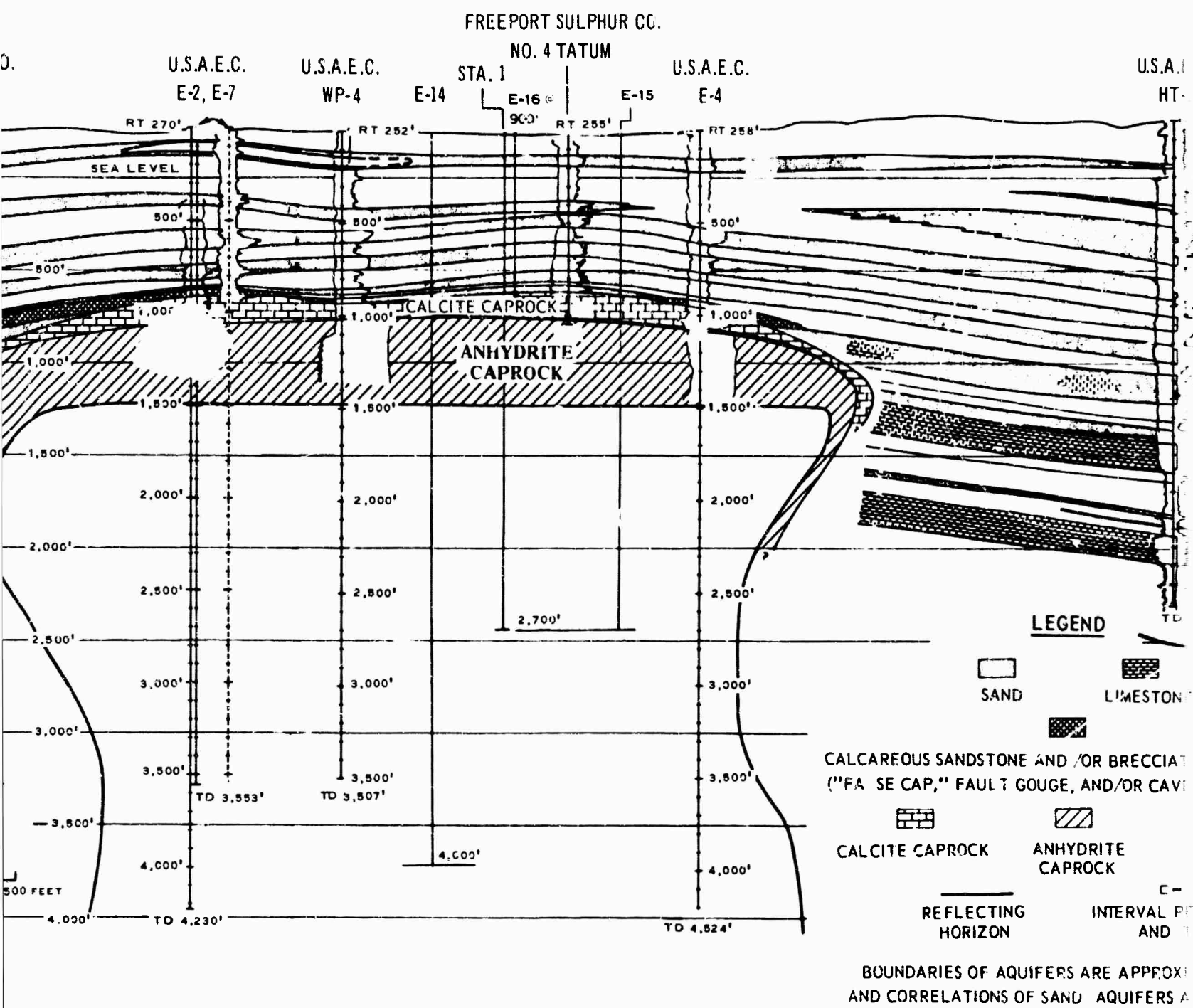


Figure 7.3 Southwest-northeast

A



North-northeast section through Tatum Dome.



FREEPORT SULPHUR CO.

NO. 4 TATUM

STA. 1

U.S.A.E.C.  
E-2, E-7

U.S.A.E.C.  
WP-4

E-14

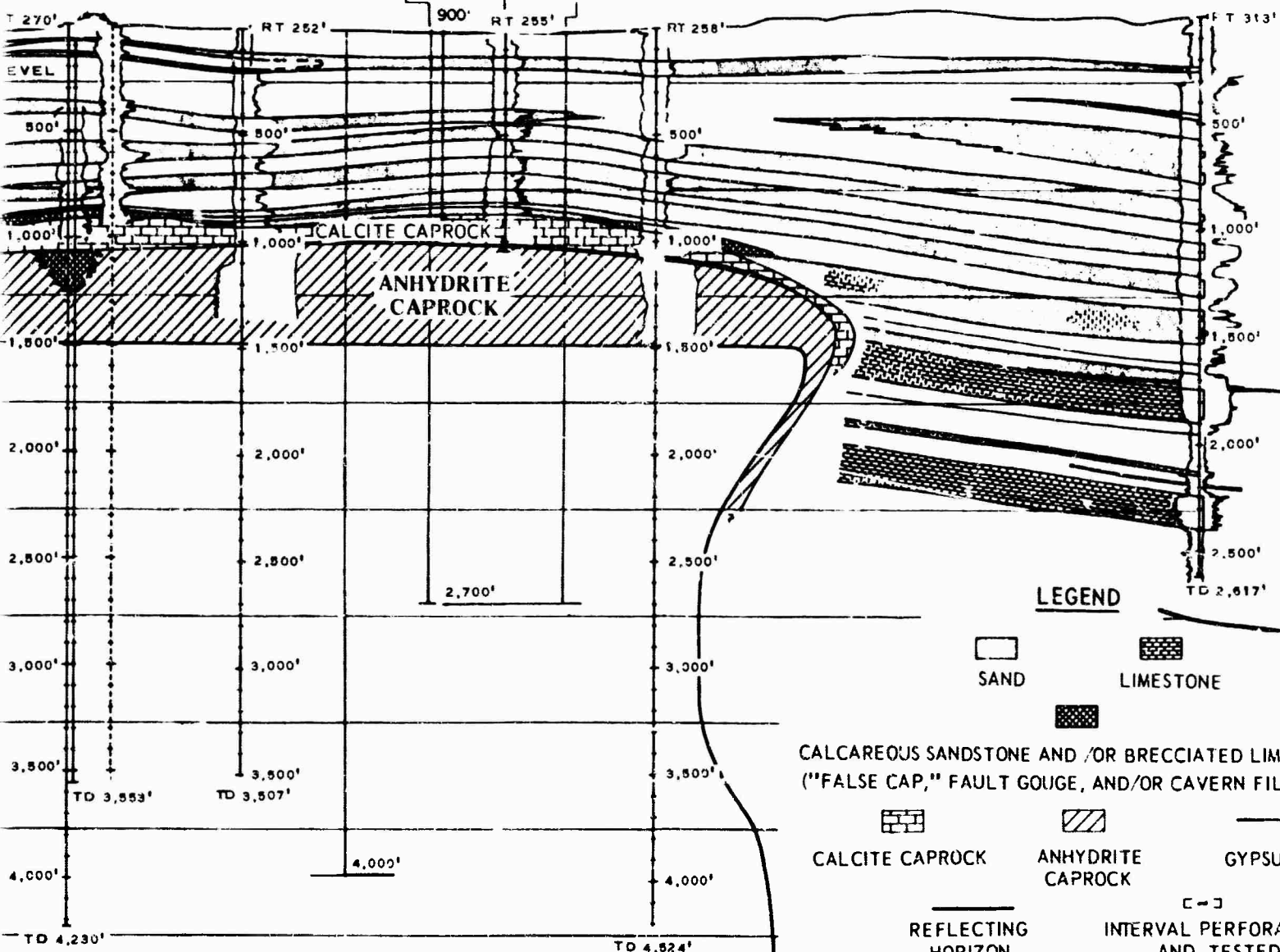
E-16

E-15







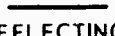

U.S.A.E.C.  
E-4

U.S.A.E.C.  
HT-1

NE  
A'



LEGEND

-  SAND
-  LIMESTONE
-  CALCAREOUS SANDSTONE AND /OR BRECCIATED LIMESTONE ("FALSE CAP," FAULT GOUGE, AND/OR CAVERN FILLING)
-  CALCITE CAPROCK
-  ANHYDRITE CAPROCK
-  GYPSUM
-  REFLECTING HORIZON
-  INTERVAL PERFORATED AND TESTED

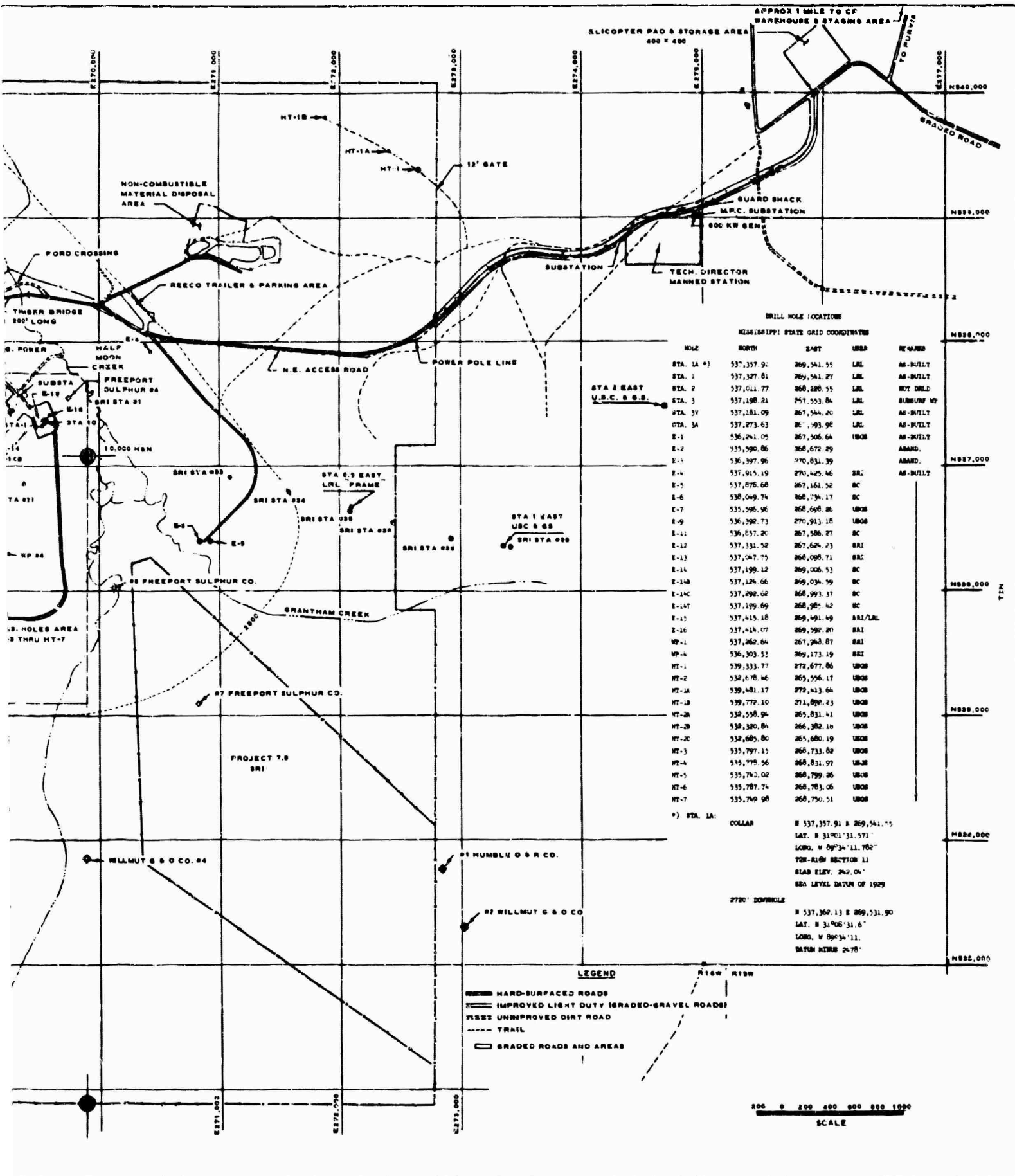
BOUNDARIES OF AQUIFERS ARE APPROXIMATE ONLY, AND CORRELATIONS OF SAND AQUIFERS ARE INFERRED

Section through Tatum Dome.

C

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DRILL HOLE LOCATIONS

MISSISSIPPI STATE GRID COORDINATES

HOLE	NORTH	EAST	USGS	REMARKS
STA. 1A *	537,357.91	269,541.55	LAL	AS-BULLY
STA. 1	537,327.81	269,541.27	LAL	AS-BULLY
STA. 2	537,011.77	268,220.55	LAL	NOT DRILL
STA. 3	537,198.21	257,553.84	LAL	SUBURBY MP
STA. 3A	537,181.09	267,544.20	LAL	AS-BULLY
STA. 3B	537,273.63	267,593.98	LAL	AS-BULLY
E-1	536,241.05	267,506.64	UNOS	AS-BULLY
E-2	535,590.86	268,672.29	UNOS	ABAND.
E-3	536,397.96	270,831.39	UNOS	ABAND.
E-4	537,915.19	270,425.46	BAI	AS-BULLY
E-5	537,876.68	267,161.52	BC	
E-6	536,049.74	268,734.17	BC	
E-7	535,598.96	268,698.26	UNOS	
E-8	536,392.73	270,913.18	UNOS	
E-9	536,657.20	267,586.27	BC	
E-10	537,331.52	267,624.23	BAI	
E-11	537,047.75	268,098.71	BAI	
E-12	537,199.12	269,006.53	BC	
E-13	537,124.66	269,034.59	BC	
E-14	537,292.62	268,993.37	BC	
E-15	537,199.69	268,987.42	BC	
E-16	537,415.18	269,491.49	BAI/LAL	
E-17	537,414.07	269,592.20	BAI	
MP-1	537,262.64	267,243.87	BAI	
MP-2	536,393.52	269,173.19	BAI	
MT-1	539,333.77	272,677.86	UNOS	
MT-2	532,678.46	265,956.17	UNOS	
MT-3	539,481.17	272,413.64	UNOS	
MT-4	539,772.10	271,892.23	UNOS	
MT-5	532,558.94	265,831.41	UNOS	
MT-6	532,380.84	266,382.16	UNOS	
MT-7	532,685.80	265,680.19	UNOS	
MT-8	535,797.13	266,733.82	UNOS	
MT-9	535,775.56	268,831.97	UNOS	
MT-10	535,740.02	268,799.26	UNOS	
MT-11	535,787.74	268,783.06	UNOS	
MT-12	535,749.98	268,750.51	UNOS	

\* STA. 1A: COLLAR N 537,357.91 E 269,541.55  
LAT. N 31°01'31.571"  
LONG. W 89°34'11.762"  
TOP-RIGH SECTION 11  
SLAB ELEV. 242.04'  
SEA LEVEL DATUM OF 1929

770' DOWNDROP N 537,362.13 E 269,531.90  
LAT. N 31°06'31.6"  
LONG. W 89°34'11.1"  
DATUM HEIGHT 247.0'

**LEGEND**

- HARD-SURFACED ROADS
- IMPROVED LIGHT DUTY (GRADED-GRAVEL ROADS)
- UNIMPROVED DIRT ROAD
- TRAIL
- GRADED ROADS AND AREAS

**SCALE**

0 200 400 600 800 1000

opposite site map.

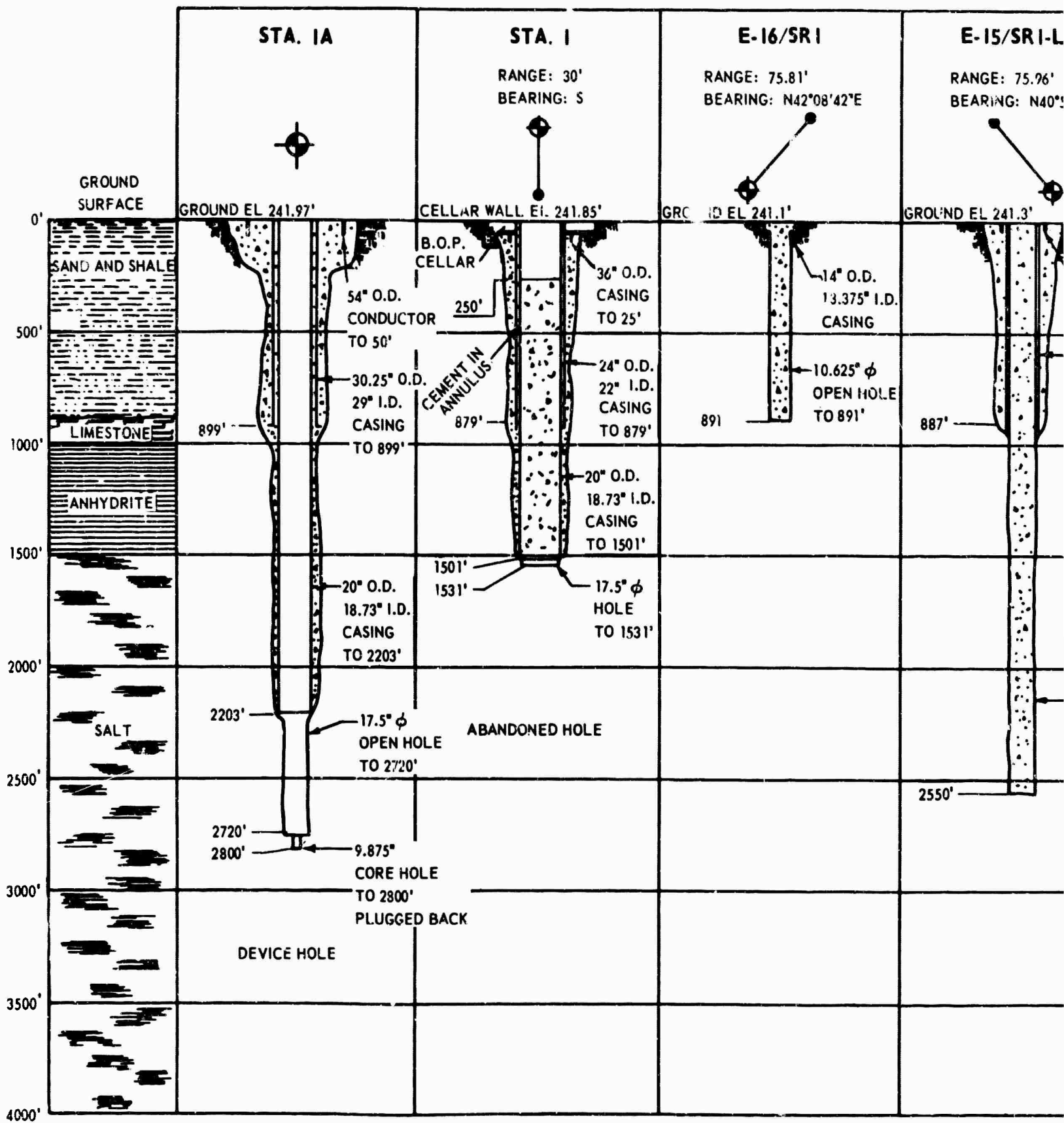
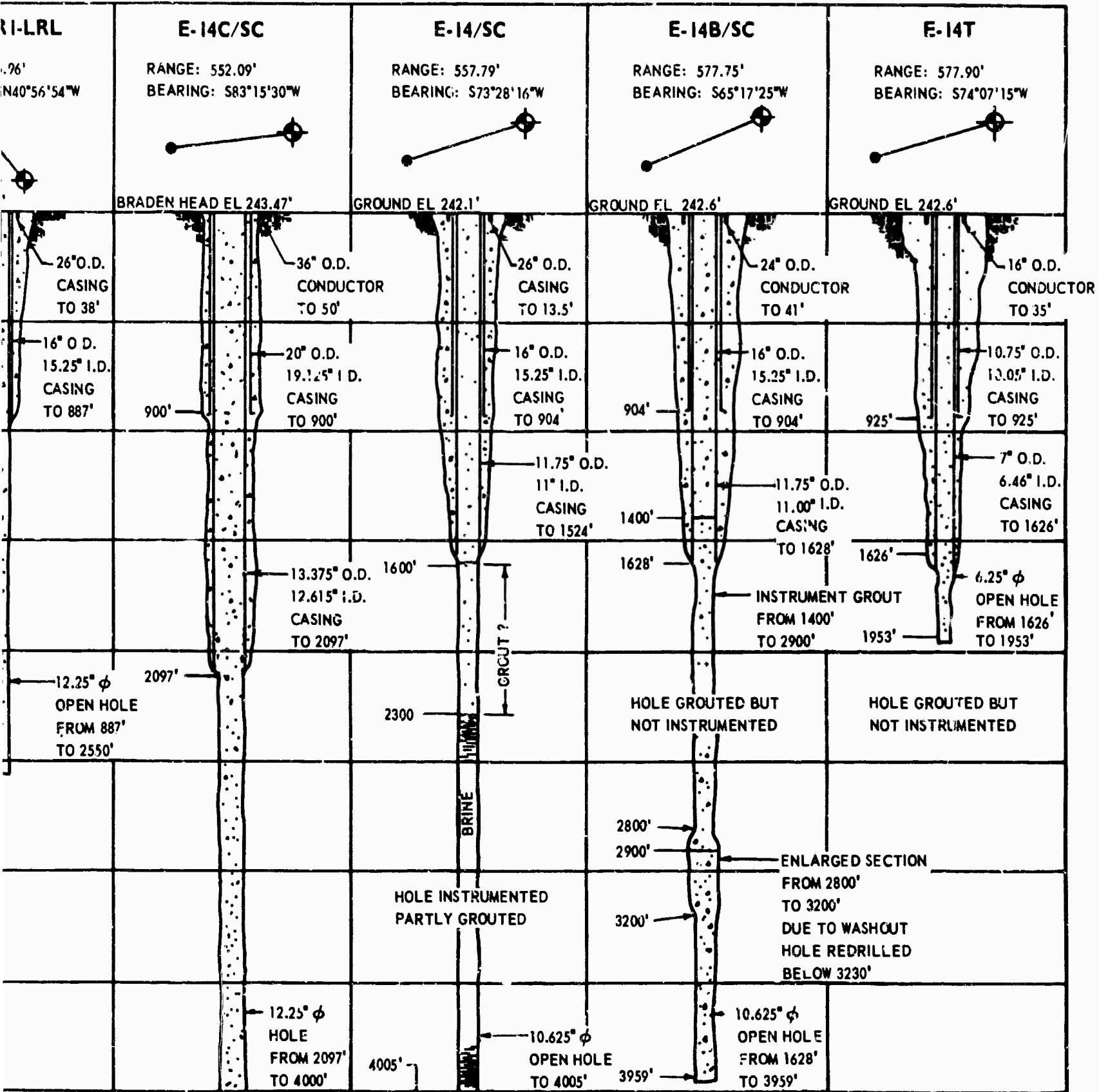


Figure 7.5 Casing schedule and grouting plan for holes E-



E-14, E-14B, E-14C, E-14T, E-15, E-16, and stations 1 and 1-A.

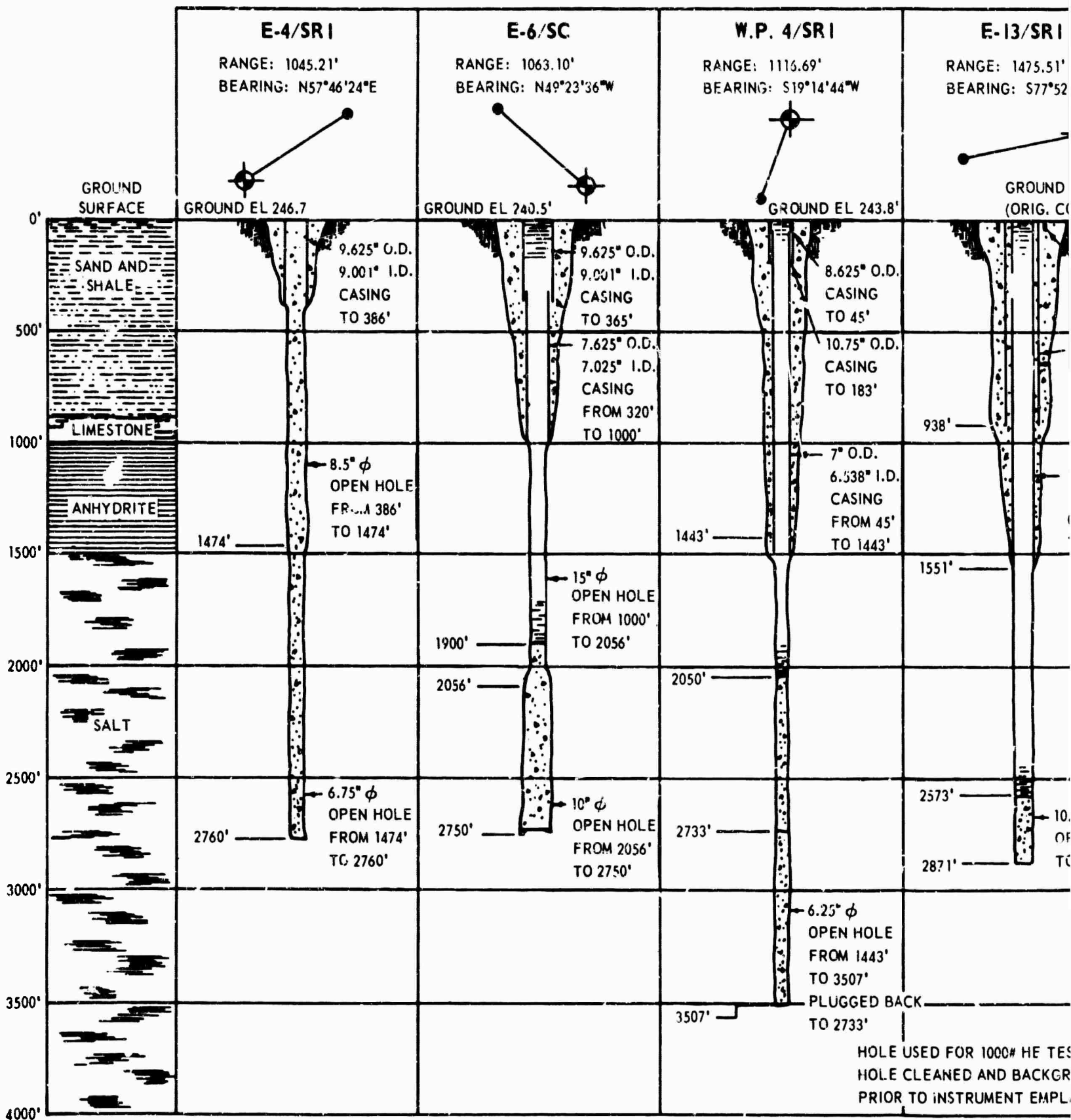
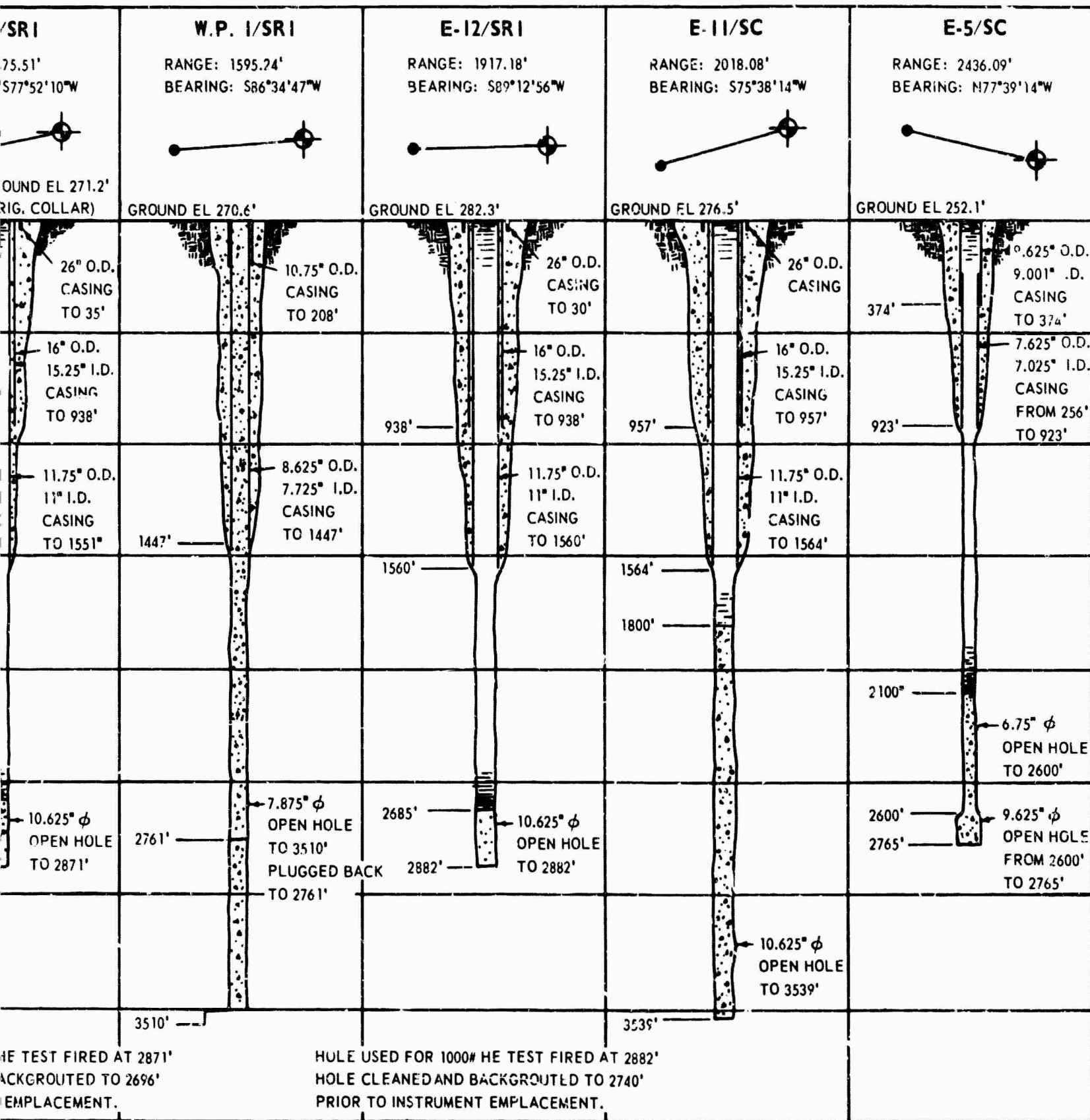


Figure 7.6 Casing schedule and grouting plan for holes



holes E-4, E-5, E-6, E-11, E-12, E-13, WP-1, and WP-4.

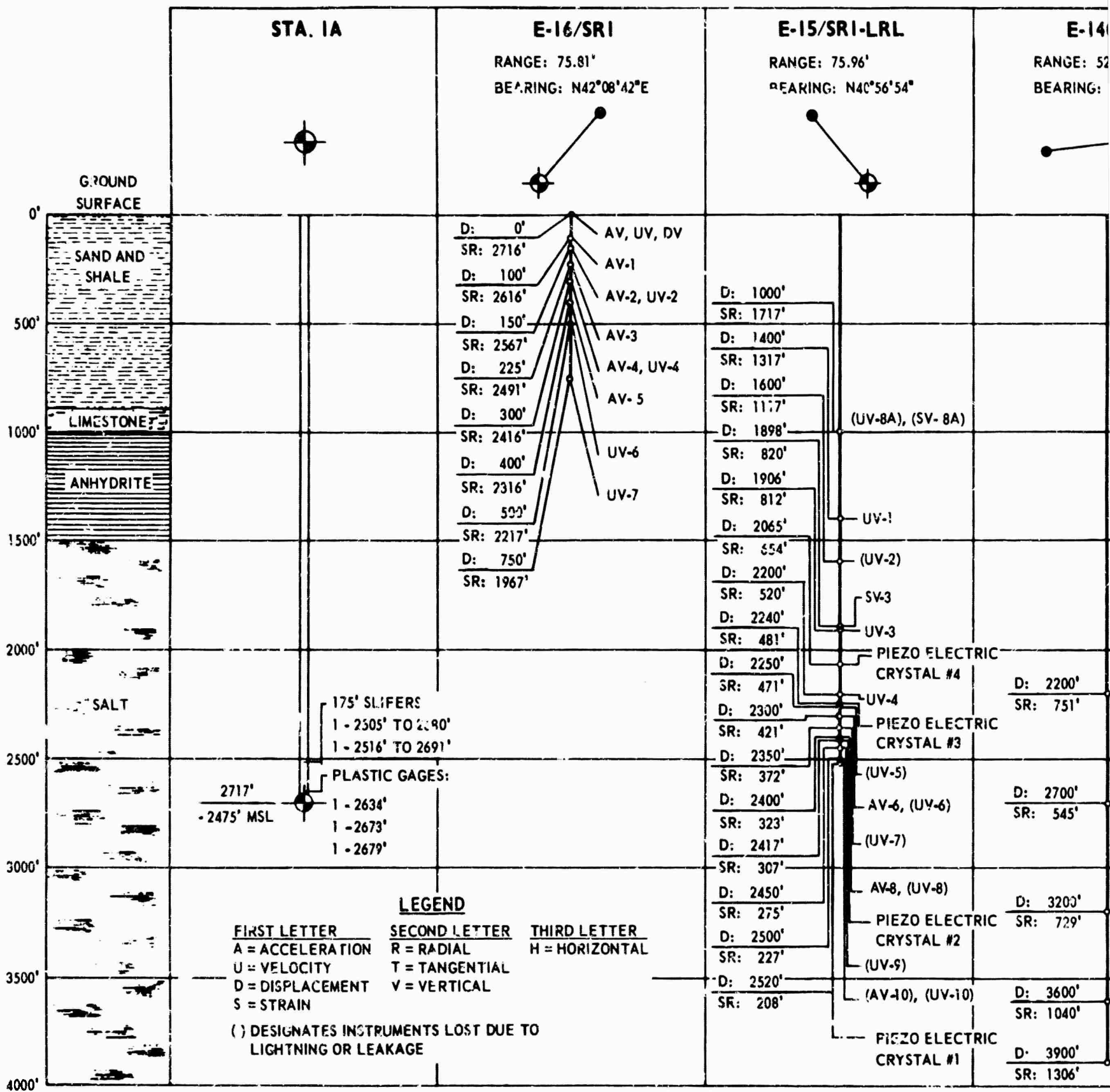


Figure 7.7 Subsurface instrument plan for holes E-4, E-14, E-14H



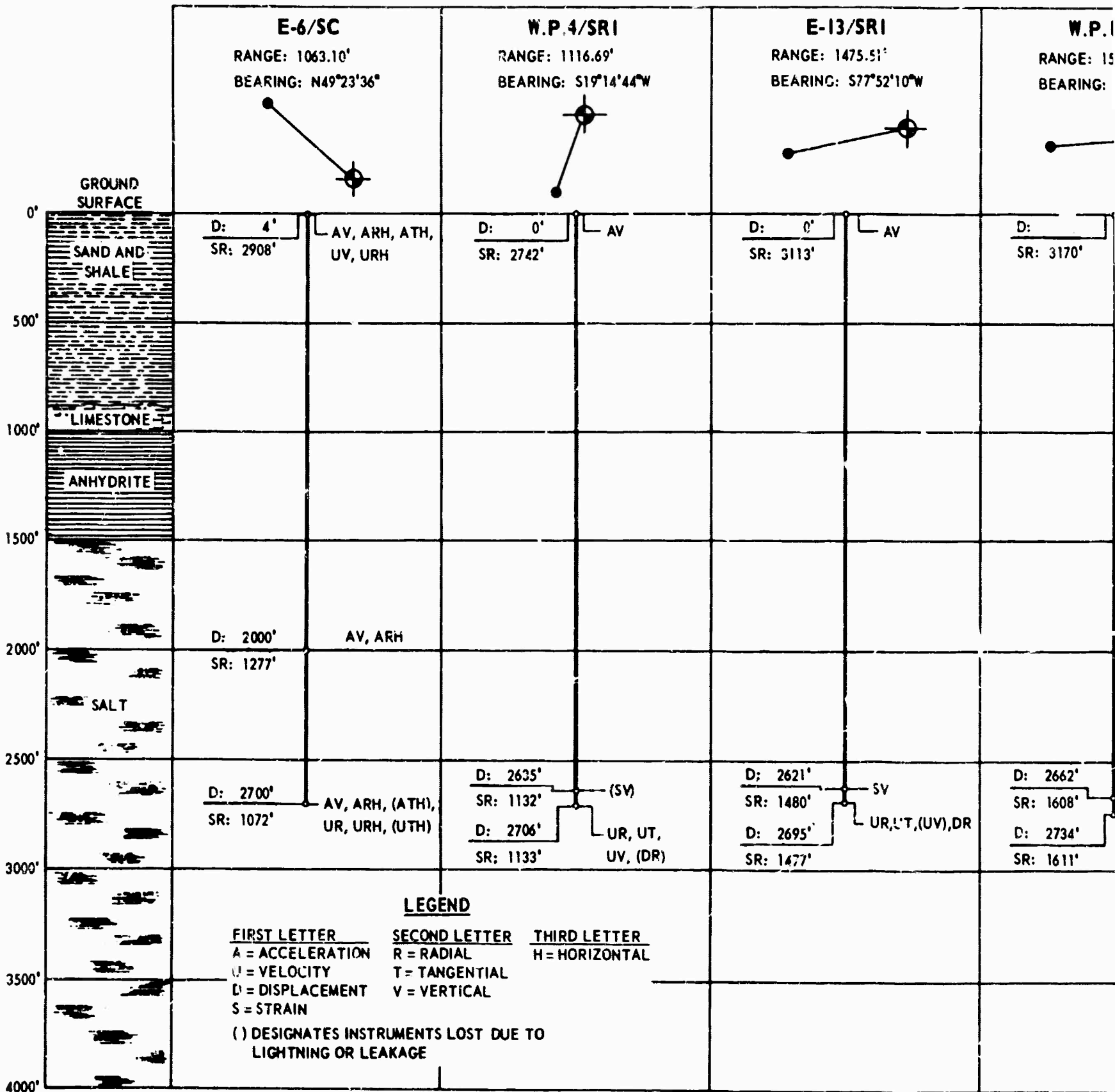


Figure 7.8 Subsurface instrument plan for holes E-5,



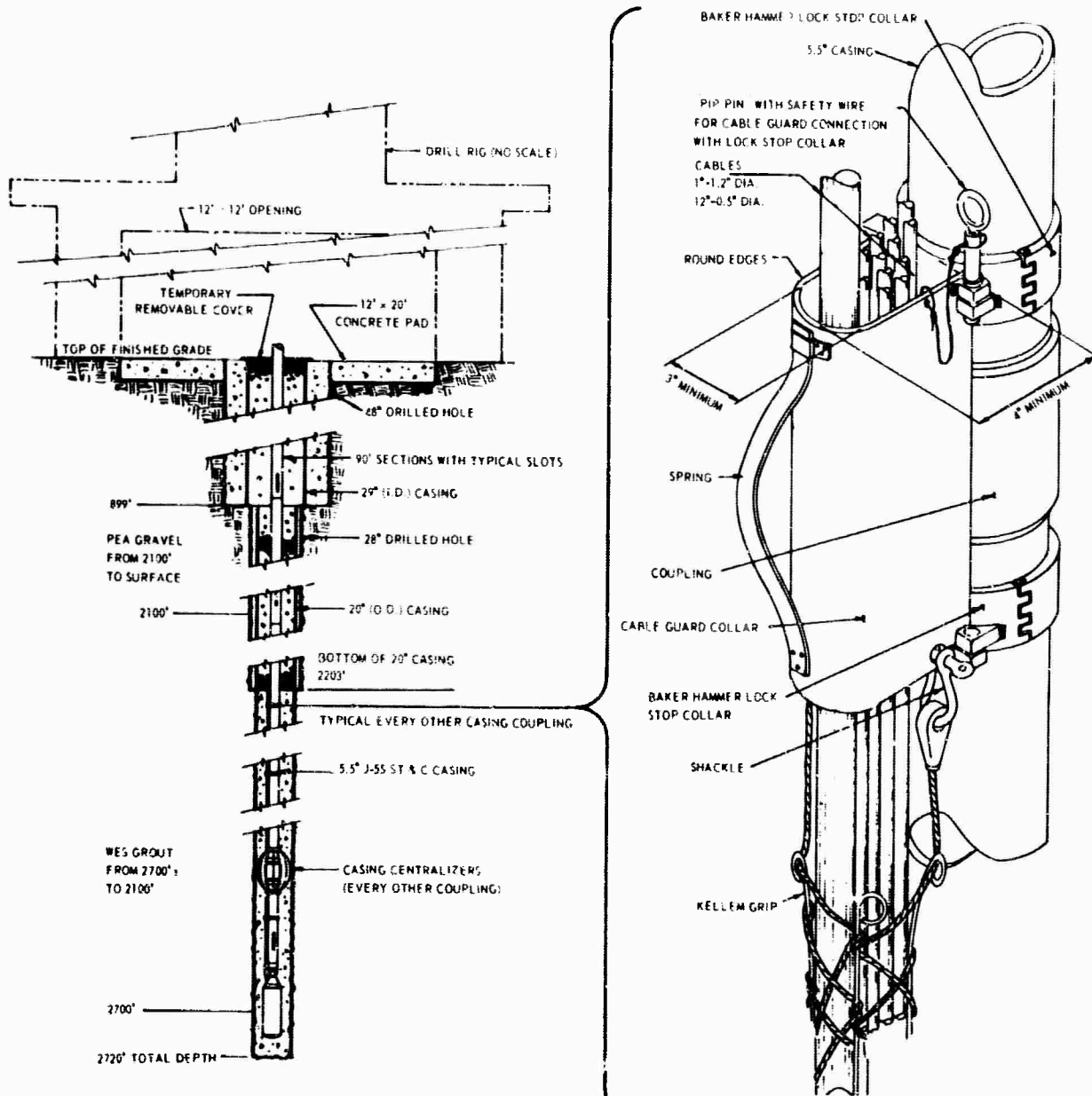


Figure 7.9 Station 1-A hole section.

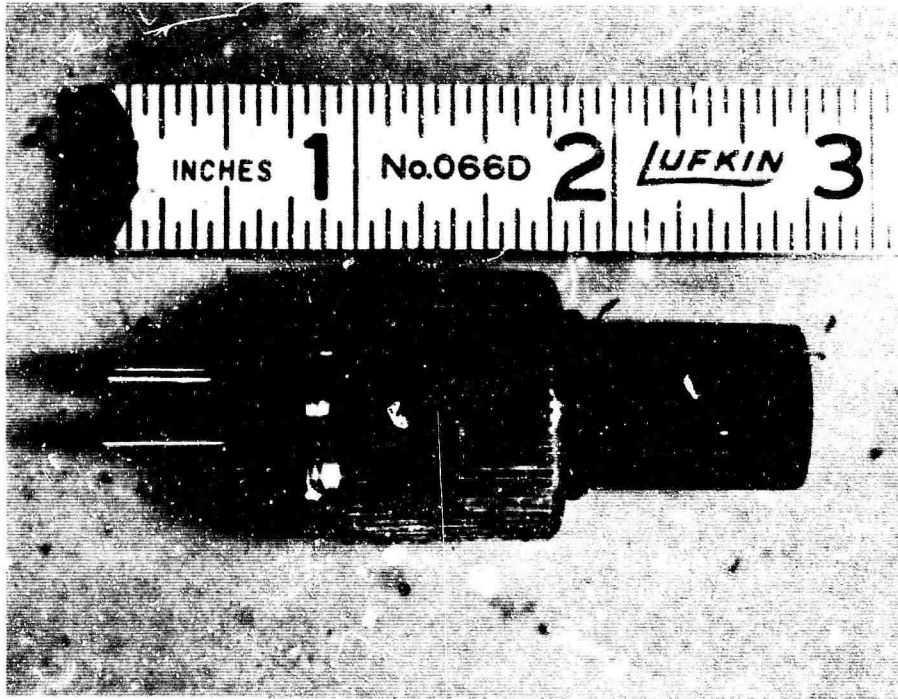


Figure 7.10 Thermistor probe, station 1-A.

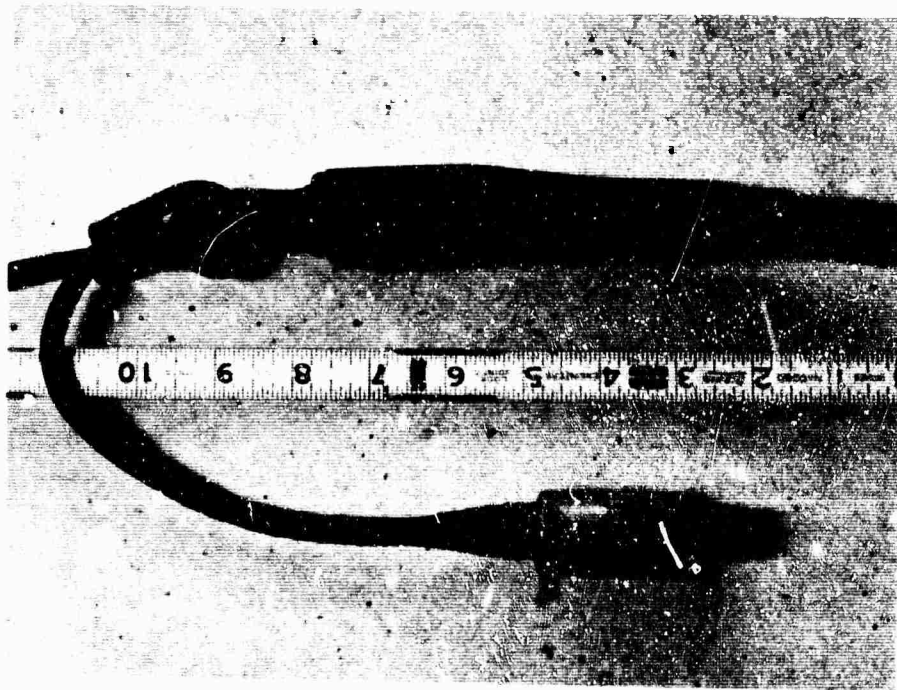


Figure 7.11 Thermistor probe assembly, station 1-A.

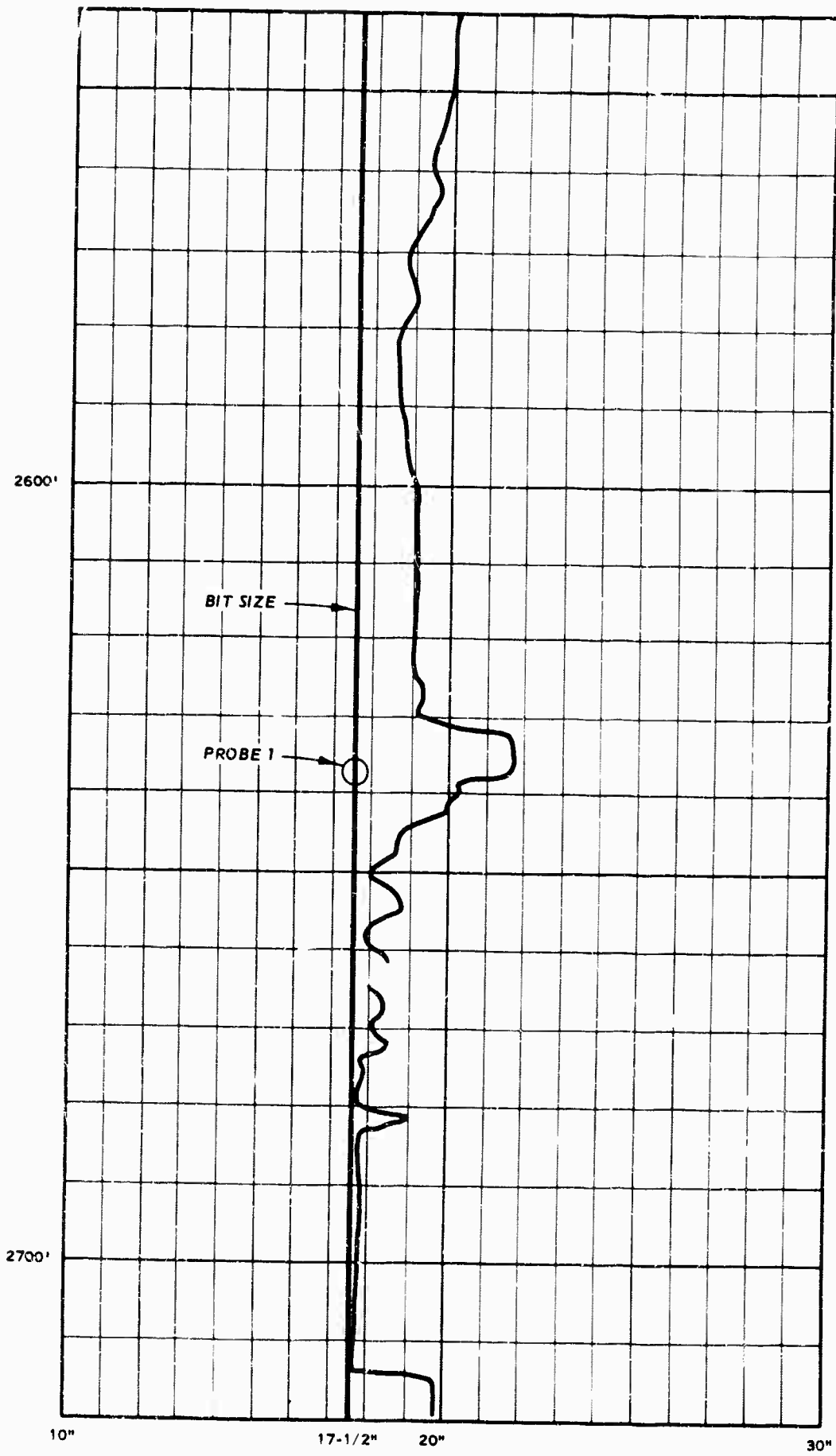


Figure 7.12 Caliper-log section, station 1-A.

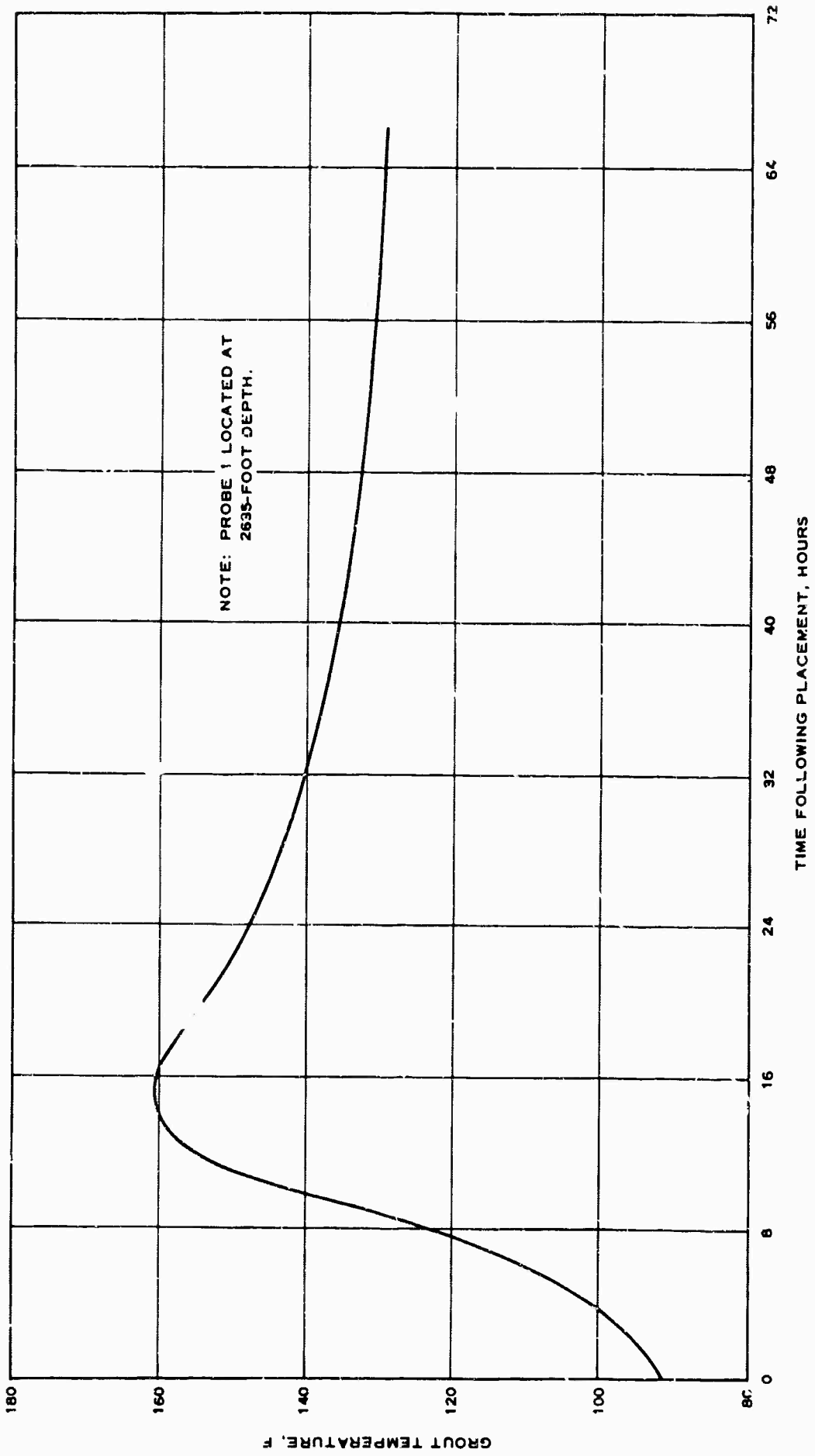


Figure 7.13 Grout temperature versus time (probe 1).

CHAPTER 8  
CONCLUSIONS

8.1 GROUT MIXTURES

Grout mixtures were successfully developed to meet all job requirements. Modifying mixtures to meet depressed temperature requirements did not appreciably alter the physical properties of the mixtures.

8.2 INSTRUMENT HOLE GROUTING

With the exception of hole E-14, all instrument holes were successfully grouted. Difficulties were experienced in other holes, particularly E-6; however, various remedial actions solved these problems.

8.3 STATION 1-A STEMMING

The stemming operation for station 1-A was highly successful in all respects.

8.4 FIELD GROUTING SYSTEMS

Modifications and the addition of supplemental mixing equipment to the grouting systems of the Dowell and Halliburton Companies considerably improved the quality control of the grout mixtures. This improved quality control is believed to have been largely responsible for the successful grouting of the device and instrument holes.

## APPENDIX A

### INSTRUMENTS USED TO DETERMINE ELEVATION OF GROUT IN HOLES

#### A.1 PRESSURE-DIFFERENTIAL SWITCH

The basic idea in density indication by pressure-differential switches is that the difference in the pressure at two points which are a fixed distance apart is a direct measure of the density. This can be shown as follows. The pressure at any depth in a fluid is  $P = ph$ , where  $P$  is the pressure,  $p$  the density, and  $h$  the depth. The difference in pressure ( $\Delta P$ ) between two points at depths  $h_1$  and  $h_2$  is

$$\Delta P = p (h_1 - h_2)$$

If the distance ( $h_1 - h_2$ ) is fixed,  $\Delta P$  is directly proportional to the density of the fluid.

The switches were designed to activate when the density of the fluid in which they were immersed equaled the density of the grout. The final design was developed in cooperation with the Pall Corporation of Glen Cove, N. Y., which supplied the switches in a pressureproof casing. A preliminary design is shown in Figure A.1. The upper part of the switch is connected to a pressure-sensing diaphragm by a hydraulic hose filled with water and the upper end of the hose is sealed with a soft rubber diaphragm (see Figure A.1). In the final design, the bottom port, which is open to the fluid in Figure A.1, was also filled with a pressure-transmitting fluid and closed by a diaphragm, thereby protecting the pressure-sensing elements from large particles which could cause erroneous indications. The activating pressure differential was also changed from 1 psid to 0.5 psid in the final design

to permit shortening the length of the hose.

Laboratory tests showed this device to be sensitive to a minimum density difference of 10 pcf. The presence of grout is indicated by a simple battery and lamp circuit (Figure A.2), i.e. the light goes on when the grout surrounds the upper port on the pressure switch.

#### A.2 DIFFERENTIAL TRANSFORMER METHOD

Differential transformer model D, consisting of a primary and a secondary coil wound on a plastic frame, is shown in Figures A.3 to A.6. This model operates as an iron-core differential transformer using the floating capsule principle. An electromotive force is induced in the secondary coil by a low voltage (0 to 12 volts, 60-cycle ac) applied to the primary coil with the capsule in the core of the coils, and is changed when the capsule is floated out of the core. This change (approximately 1 ma) is easily detected on a milliammeter (Figure A.5) that indicates a full-scale deflection with a change of 1 ma. Equipment needed for operation of this detector is shown in Figure A.6.



Figure A.1 Pressure switch with high-pressure port open and low-pressure port attached to hose.

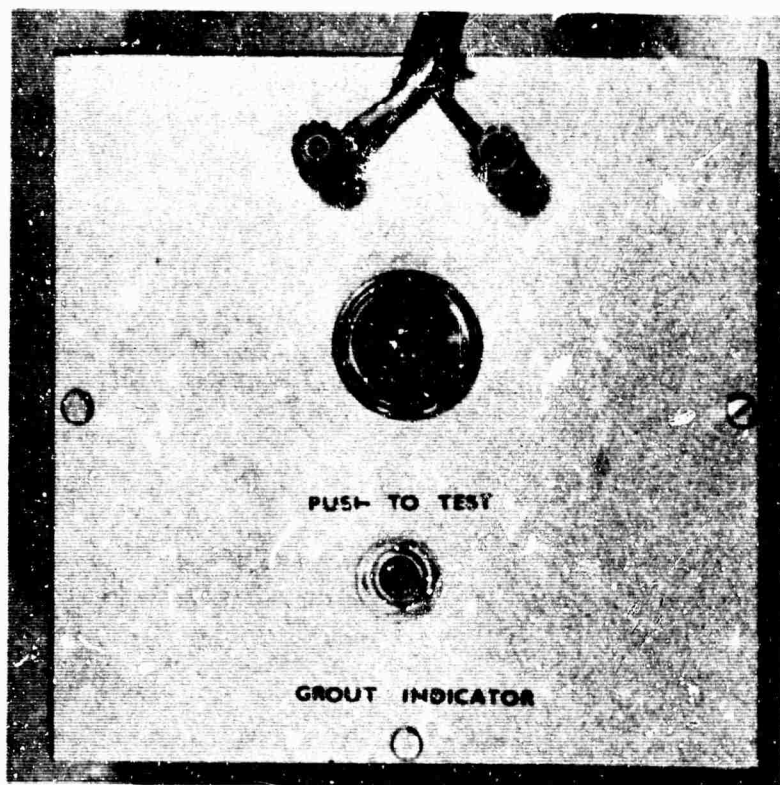


Figure A.2 Box for monitoring pressure switch and indicating when grout surrounds switch.

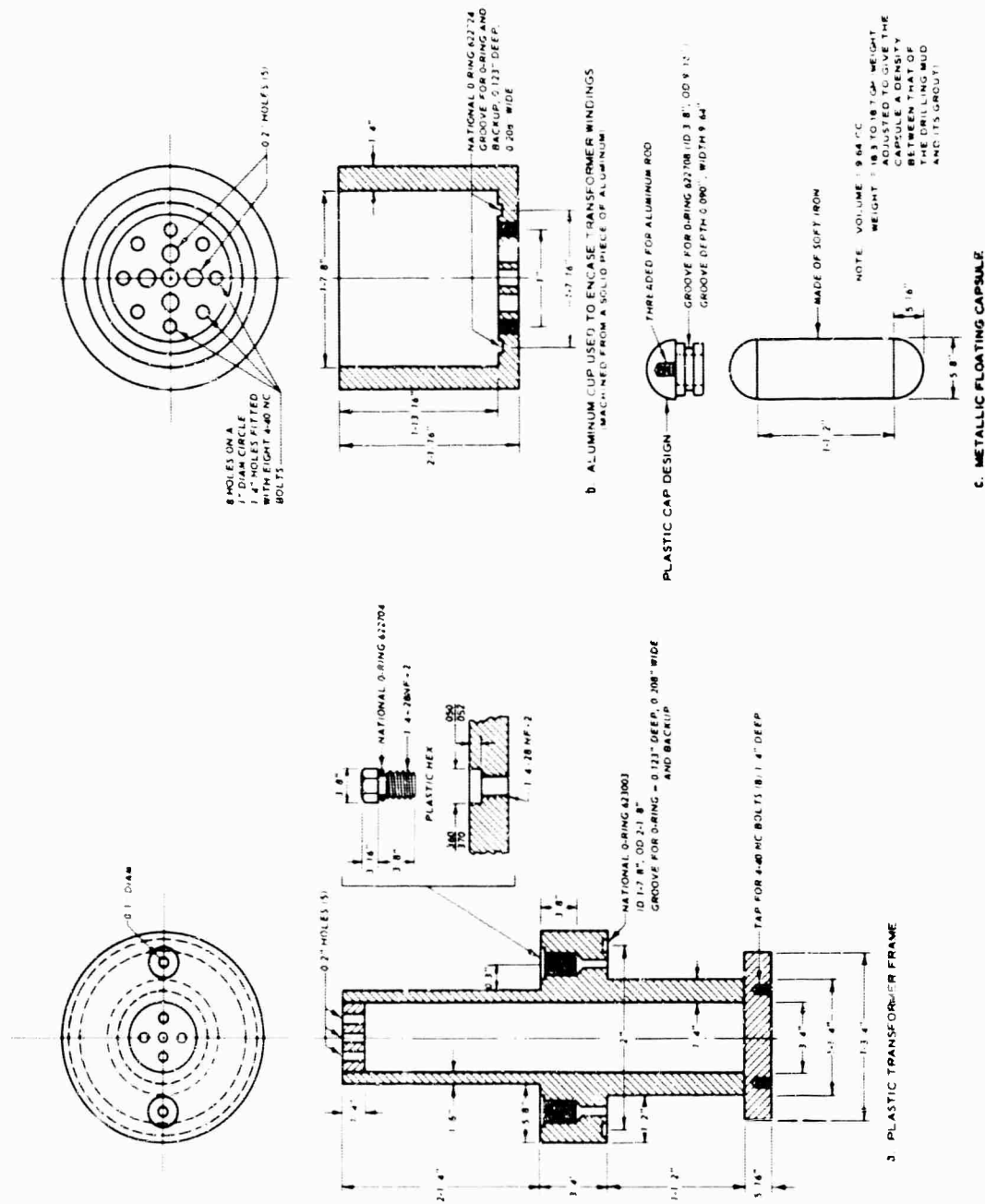
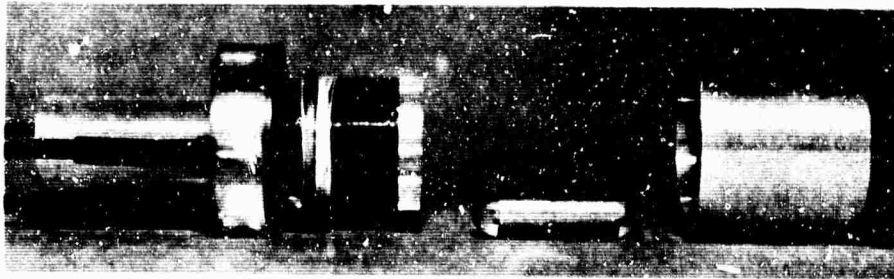
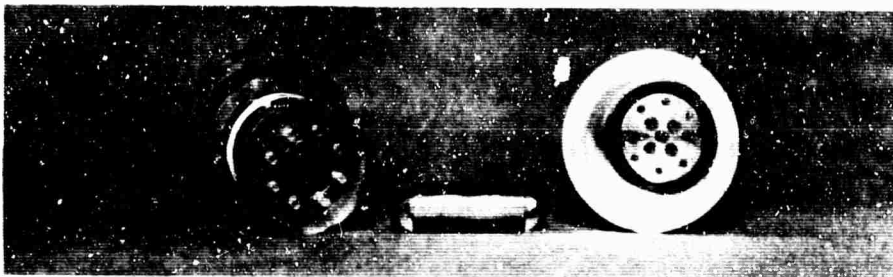


Figure A.3 Differential transformer (model D).



a. Side view.



b. End view.

Figure A.4 Transformer detector (model D).

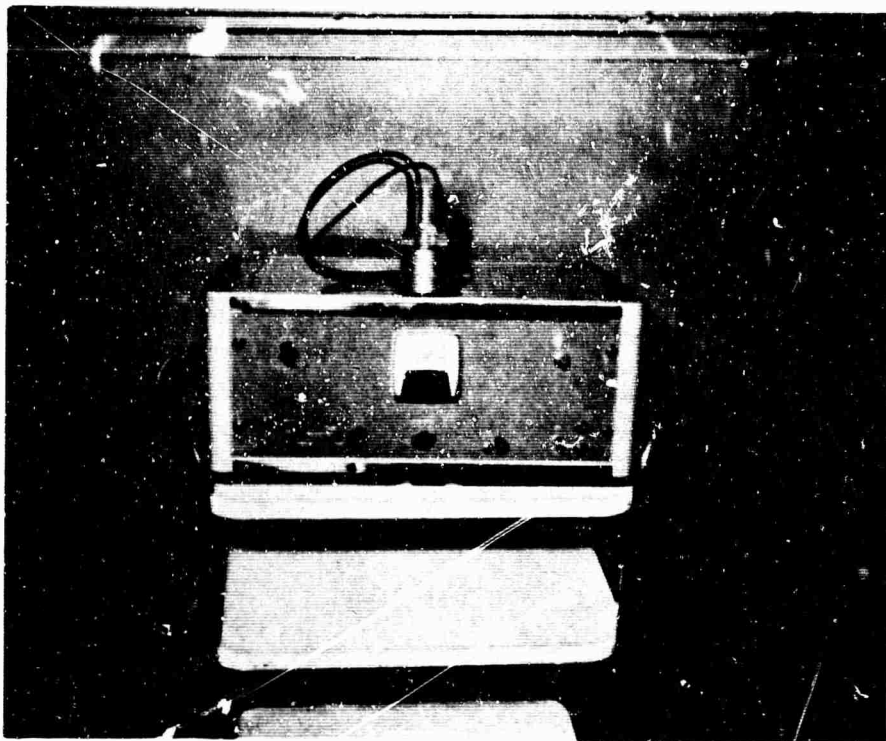


Figure A.5 Transformer detector on top of milliammeter that is used to monitor the model D detector.

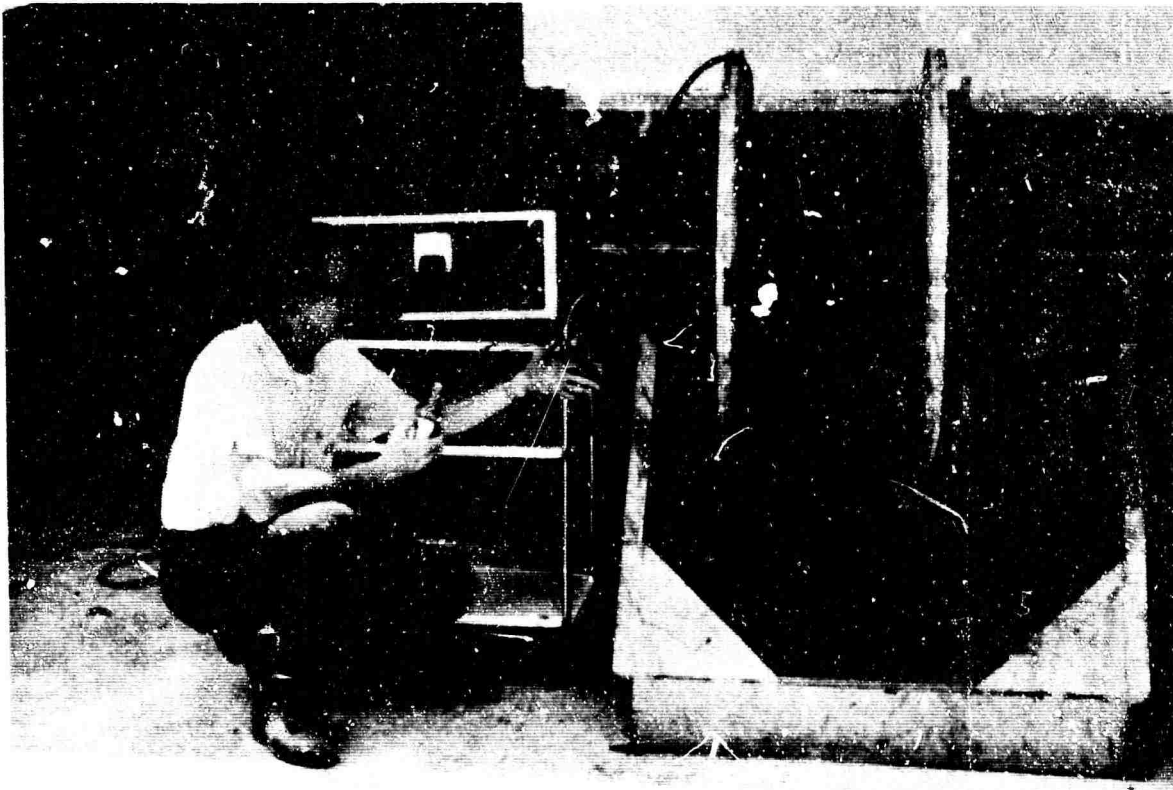


Figure A.6 Equipment for operating a transformer detector includes the detector (in right hand of operator), milliammeter (on cart), and spool of electrical cable.

TECHNICAL AND SAFETY PROGRAM REPORTS SCHEDULED FOR ISSUANCE  
BY AGENCIES PARTICIPATING IN PROJECT DRIBBLE

SAFETY REPORTS

<u>Agency</u>	<u>Report No.</u>	<u>Subject or Title</u>
USWB	VUF-1020	Meteorological Documentation and Radiation Protection
USPHS	VUF-1021	Final Report of Off-site Surveillance
USBM	VUF-1022	Pre and Post-Shot Safety Inspection of Oil and Gas Facilities Near Project Dribble
USGS	VUF-1023	Analysis of Geohydrology of Tatum Salt Dome
USGS	VUF-1024	Analysis of Aquifer Response
REECo	VUF-1025	On-Site Health and Safety Report
RFB, Inc.	VUF-1026	Analysis of Dribble Data on Ground Motion and Containment - Safety Program
H-NSC	VUF-1027	Ground Water Supply
FAA	VUF-1028	Federal Aviation Agency Airspace Advisory
H&N	VUF-1029	Summary of Pre and Post-Shot Structural Survey Reports
JAB	VUF-1030	Structural Response of Residential-Type Test Structures in Close Proximity to an Underground Nuclear Detonation
JAB	VUF-1031	Structural Response of Tall Industrial and Residential Structures to an Underground Nuclear Detonation.

NOTE: The Seismic Safety data will be included in the USC&GS Technical Report VUF-3014

TECHNICAL REPORTS

<u>Agency</u>	<u>Report No.</u>	<u>Subject or Title</u>
SL	VUF-3012	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part I
SPI	VUF-3013	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part II
USC&GS	VUF-3014	Earth Vibration from a Nuclear Explosion in a Salt Dome
UED	VUF-3015	Compressional Velocity and Distance Measurements in a Salt Dome

LRL	VUF-3016	Design and Operation of a Chemical Processing Plant for Controlled Release of a Radioactive Gas from the Cavity of a Nuclear Explosion in Salt
LRL	PNE-3002 *	Response of Test Structures to Ground Motion from an Underground Nuclear Explosion
SRI	VUF-3017	Feasibility of Cavity Pressure and Temperature Measurements for a Decoupled Nuclear Explosion
LRL	VUF-3018	Background Engineering Data and Summary of Instrumentation for a Nuclear Test in Salt
WES	VUF-3019	Laboratory Design and Analyses and Field Control of Grouting Mixtures Employed at a Nuclear Test in Salt
IRL	VUF-3020	Geology and Physical and Chemical Properties of the Site for a Nuclear Explosion in Salt
EG&G	VUF-3021	Timing and Firing

\* This report number was assigned by SAN

In addition to the reports listed above as scheduled for issuance by the Project DRIBBLE test organization, a number of papers covering interpretation of the SALMON data are to be submitted to the American Geophysical Union for publication. As of February 1, 1965, the list of these papers consists of the following:

<u>Title</u>	<u>Author(s)</u>	<u>Agency(s)</u>
Shock Wave Calculations of Salmon	L. A. Rogers	IRL
Nuclear Decoupling, Full and Partial	D. W. Patterson	IRL
Calculation of P-Wave Amplitudes for Salmon	D. L. Springer and W. D. Hurdlow	IRL
Travel Times and Amplitudes of Salmon Explosion	J. N. Jordan W. V. Mickey W. Helderbran	USC&GS AFTAC UED
Detection, Analysis and Interpretation of Teleseismic Signals from the Salmon Event	A. Archambeau and E. A. Flinn	SDC
Epicenter Locations of Salmon Event	E. Herrin and J. Taggart	SMU USC&GS
The Post-Explosion Environment Resulting from the Salmon Event	D. E. Rawson and S. M. Hansen	IRL
Measurements of the Crustal Structure in Mississippi	D. H. Warren J. H. Healy W. H. Jackson	USGS

All but the last paper in the above list will be read at the annual meeting of the American Geophysical Union in April 1965.

LIST OF ABBREVIATIONS FOR TECHNICAL AGENCIES

BR LTD	Barringer Research Limited Rexdale, Ontario, Canada	RFB, INC.	R. F. Beers, Inc. Alexandria, Virginia
ERDL	Engineering Research Development Laboratory Fort Belvoir, Virginia	SDC	Seismic Data Center Alexandria, Virginia
FAA	Federal Aviation Agency Los Angeles, California	EG&G	Edgerton, Germeshausen & Grier, Inc. Las Vegas, Nevada
GDMRADA	U. S. Army Geodesy, Intelli- gence and Mapping Research and Development Agency Fort Belvoir, Virginia	SL	Sandia Laboratory Albuquerque, New Mexico
H-NSC	Hazleton-Nuclear Science Corporation Palo Alto, California	SMU	Southern Methodist University Dallas, Texas
H&N, INC	Holmes & Narver, Inc. Los Angeles, California Las Vegas, Nevada	SRI	Stanford Research Institute Menlo Park, California
II	Isotopes, Inc. Westwood, New Jersey	TI	Texas Instruments, Inc. Dallas, Texas
IIEK	Itek Corporation Palo Alto, California	UA	United Aircraft El Segundo, California
JAB	John A. Blume & Associates Research Division San Francisco, California	UED	United Electro Dynamics, Inc. Pasadena, California
IRL	Lawrence Radiation Laboratory Livermore, California	USBM	U. S. Bureau of Mines Washington, 25, D. C.
NRDL	U. S. Naval Radiological Defense Laboratory San Francisco, California	USC&GS	U. S. Coast and Geodetic Survey Las Vegas, Nevada
KEECO	Reynolds Electrical & Engineering Co., Inc. Las Vegas, Nevada	USGS	U. S. Geologic Survey Denver, Colorado
		USPHS	U. S. Public Health Service Las Vegas, Nevada
		USWB	U. S. Weather Bureau Las Vegas, Nevada