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Borehole Plugging Program
Plugging of ERDA No. 10 Drill Hole

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BOREHOLE PLUGGING PROGRAM PLUGGING OF ERDA NO. 10 DRILL HOLE

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ABSTRACT

A requirement exists to plug exploratory drill holes located in the proposed Waste Isolation Pilot Plant area of Southeastern New Mexico. Sandia Laboratories, in cooperation with the U.S. Army Corps of Engineers, Waterways Experiment Station, Concrete Laboratory, developed pumpable and durable cement grouts. These grouts were successfully used to plug an existing drill hole in the area. Results of this project are presented, along with comments and conclusions.

ACKNOWLEDGMENT

The plugging operations for the ERDA No. 10 drill hole were closely supervised by D. M. Walley of the Grouting Branch of the Concrete Laboratory of the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. R. A. Bendinelli, head of the Grouting Branch, actively participated in the coordination meetings and preparation for the field activities. W. E. Cunningham of Fenix & Scisson was in charge of the field activities for the drilling and plugging of the exploratory drill hole. The cementing contractor for the plugging operations was the Dowell Division of the Dow Chemical Company. The preparatory testing and development work for the specific plug mixture designs was accomplished at Dowell's Midland, Texas Division Laboratory under the direction of E. L. Shumaker, Regional Engineering Manager. All of the participating agencies were very responsive to the field needs, and the success is due to the cooperation of the above personnel and their field and lab crews.

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Introduction

Sandia Laboratories has been sponsoring the development of pumpable and durable cement grouts for use in the Borehole Plugging Program in support of the nuclear Waste Isolation Pilot Plant (WIPP). Reference 1 discusses the background and first year's results of the studies at the Concrete Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

In 1977 the decision to plug exploratory drill hole ERDA No. 10 near the WIPP site in southeastern New Mexico provided an opportunity to initiate a quality control and quality assurance program for hole plugging under field conditions. The entire batching and mixing operations were under the close supervision of personnel from the Grouting Branch of WES.

Hole History

A permit to drill ERDA No. 10 was requested in early August 1977 and approved. The hole is located in S34, T23S, R30E in Eddy County, New Mexico, 2327 ft from east line and 200 ft from north line. The location is about 15 miles east of Loving, New Mexico, near the project Gnome site. Ground level (GL) is 3371 ft.

Excavation of the 6 x 6 x 6 ft cellar was initiated on August 11. An 18-in. diameter hole was drilled from ground level to 40 ft, and an 13-3/8 in.-OD casing was set at 37 ft. The annulus was cemented to the cellar floor with 81 ft^3 of Class A cement. Mobilization of the drilling rig was completed in place on August 18. All depths in the hole are from the Kelly bushing which was 13 ft above ground level.

The initial hole diameter for the surface casing was 7-7/8 in. It was then opened to 12-1/4 in. to the depth of 805 ft. A nitrogen pocket at 675 ft unloaded the mud from the hole while making a connection in the drill string. The casing ID was 8.92 in. and was set from 805 ft to GL. The annulus was cemented on August 21 with 508 ft^3 of Class C cement with 2% calcium chloride by Dowell. The top of the cement subsided to a 51-ft depth. A second stage was placed by using 46 ft^3 of the same mix and circulating 13 ft^3 out of the annulus.

The cement surface inside the casing was tagged at 760 ft. The cement and shue were drilled out, and the hole was rotary drilled to 2095 ft with a 7-7/8 in. bit. Cores were cut to 3400 ft by using a 60-ft long core barrel with a 7-13/16 x 4-1/4 in. core bit. The bottom 120 ft was reamed and drilled to 3406 ft. Birdwell logs were run on September 9, and drill stem testing was completed on September 15.

The hole was rotary drilled to a depth of 3815 ft. Three cores were cut through the interval of 3815 to 3927 ft. The USGS logs were run on September 18, and drill stem testing was completed on September 20. Rotary drilling then deepened the hole to 4330 ft, and two cores were cut to the total depth (TD) of 4431 ft in the Bell Canyon formation. Schlumberger sonic logs and USGS logs were completed on September 26. Drill stem testing was completed on September 30, and the hole was conditioned and ready for plugging on September 30. Figure 1 shows the plugging plan, locations of drilling and coring, and approximate depths for the major geologic features.

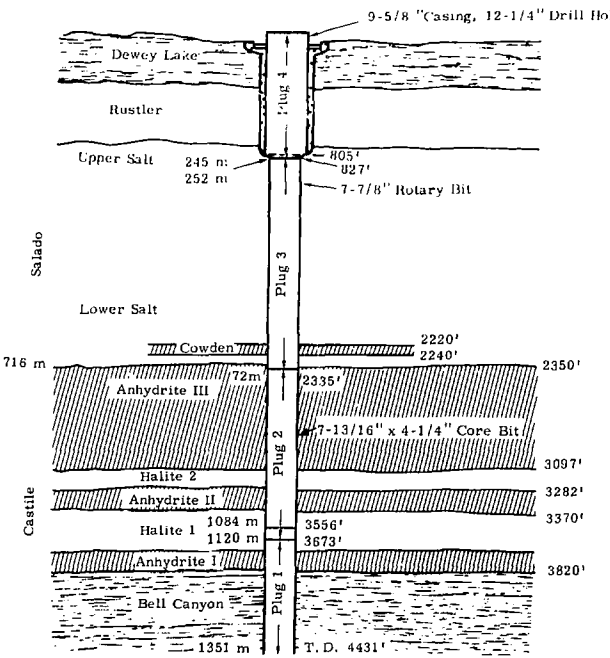


Figure 1. ERDA No. 10 Drill Hole

Plugging Plan

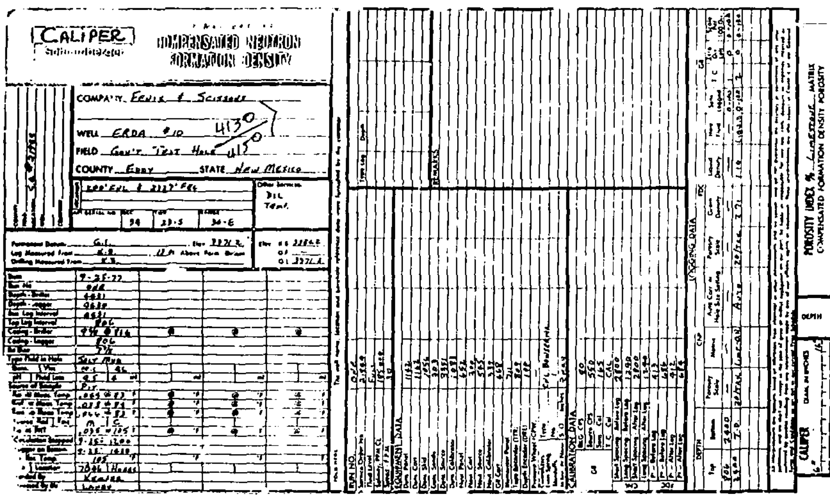
Preliminary meetings were held with two potential grouting contractors in Carlsbad on September 7-8. Sandia representatives from Division 1133 and Department 5310, Fenix & Scisson and WES participated in both meetings. The proposed plugging plan in Figure 1 listed four plugs as follows:

Plug No.	Depth (ft)	Length (ft)
1	4431-3730	701
2	3730-2300	1430
3	2300-800	1500
4	800-GL	800

These depths were intended to place the first plug from total depth up to a short distance into the Castile formation. The second and third plugs were intended to divide the distance through the salt section up to the bottom of the casing approximately in half. This would reduce formation damage from the pressure head of the fluid grout. The fourth plug filled the inside of the casing to ground level. Dowell was chosen to accomplish the plugging operations.

Dowell and Fenix & Scisson personnel held several meetings between September 8 and 30 to review the caliper logs from the hole, to determine the quantity for each plug, and to review the lab data from the Dowell Midland Laboratory for each of the mixture designs cured under pressures and temperature simulating the field conditions for each plug. Figure 2 is the caliper log for the hole which was used for determining the volume of each plug. An excess volume of 30% was used for plugs 1, 2, and 3. Inside the casing for plug 4 the excess was 20%. The following volumes were determined for each of the plugs:

Plug No.	Measured Volume (ft^3)	Excess (%)	Total Volume (ft^3)
1	319	30	414
2	800	30	1040
3	1023	30	1330
4	347	20	417



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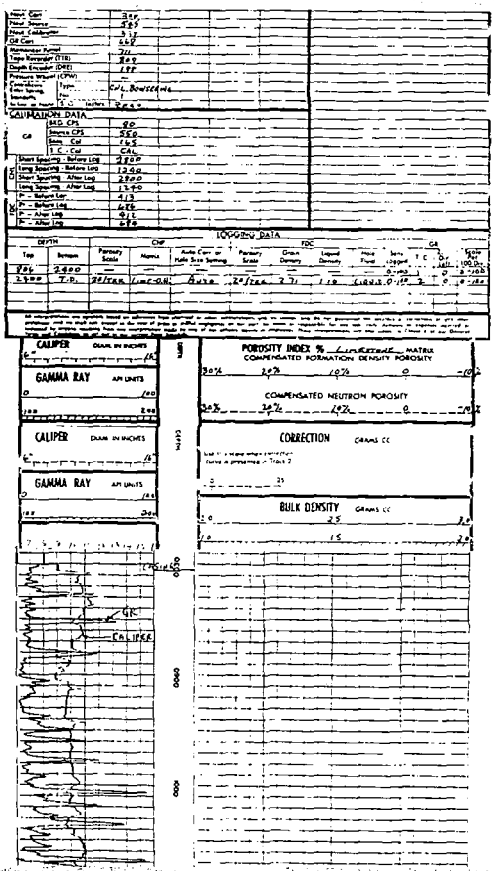
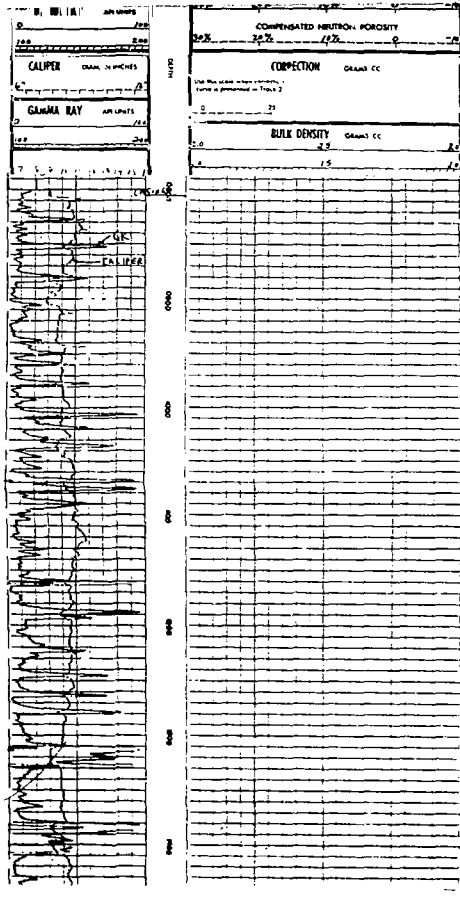


Figure 2. Caliper Log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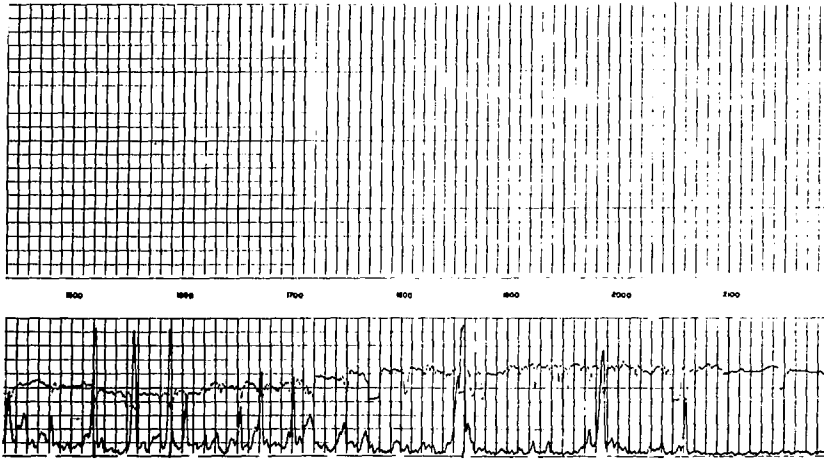
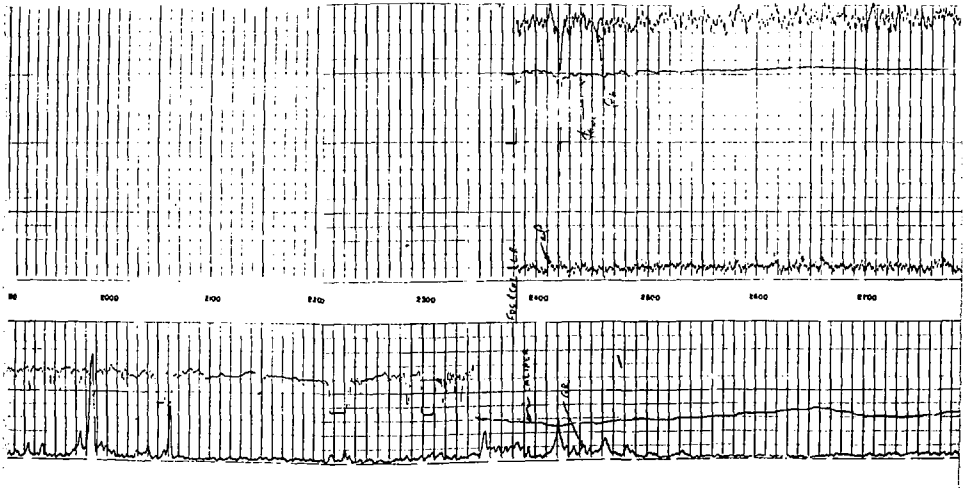


Figure 2



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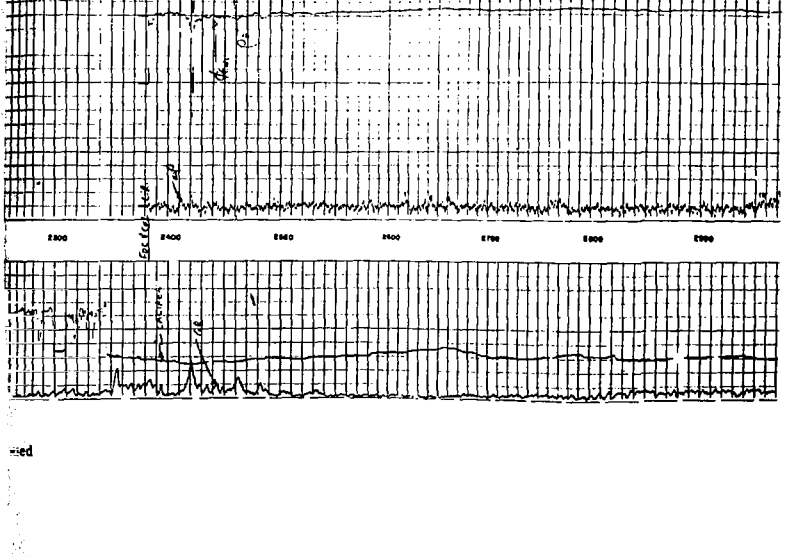

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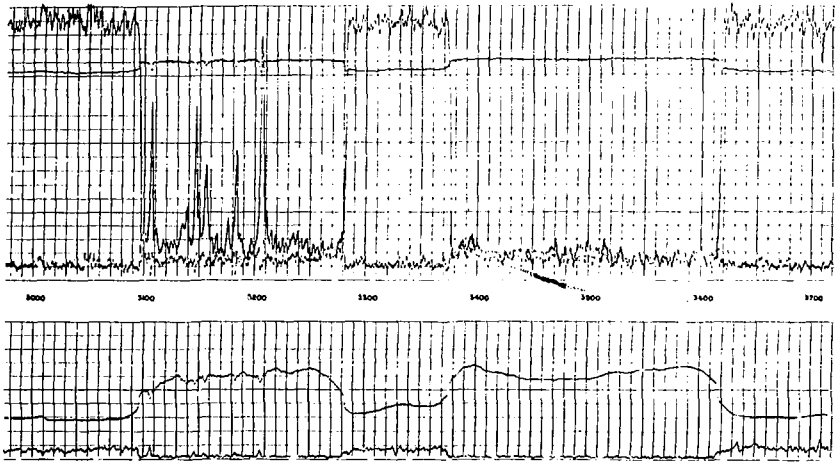


Figure 2.

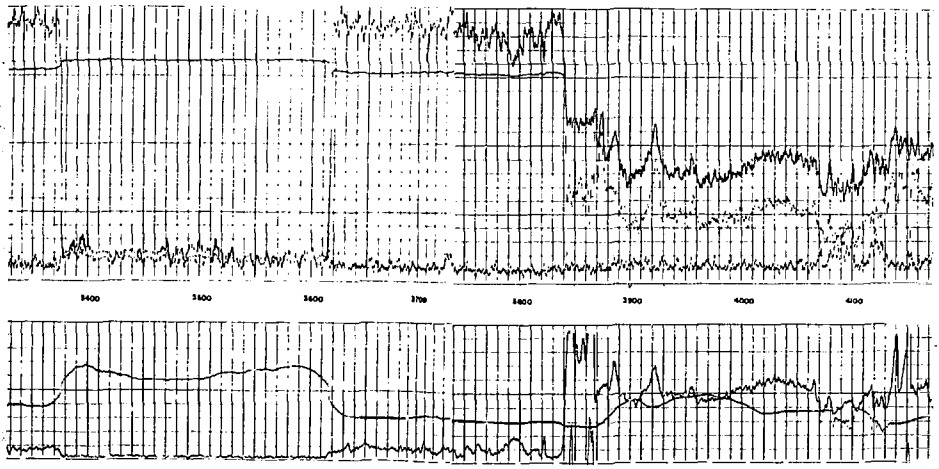
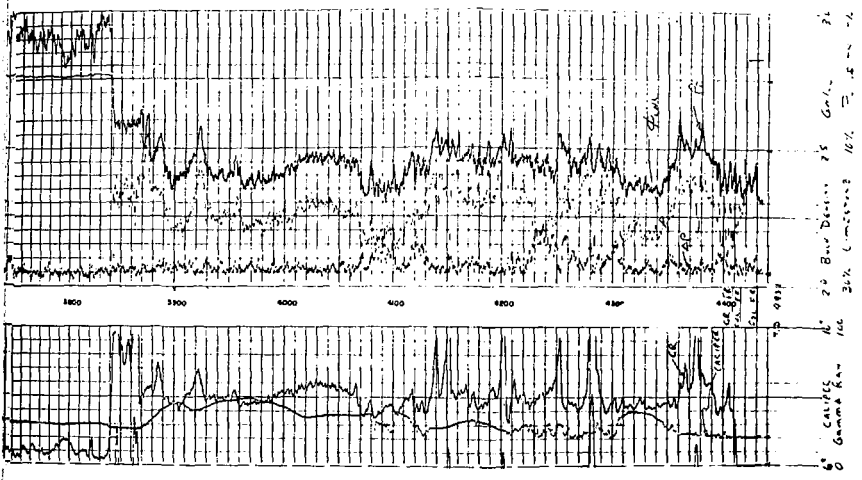


Figure 2. concluded



oncluded

Table 1 lists the weights and pertinent data for each of the three different grout mixtures. The basic grout was 30% Litepoz three (flyash)/70% Class C (SR) produced at the Maryneal plant of Lone Star Cement Company. It was supposed to have a zero C_3A content and is recommended for the severe downhole environment in the Carlsbad area. A fine granulated salt, which would dissolve in the mix water was included in the first three plug mixtures which would be in contact with the salt formation. For plugs 2 and 3, the salt content was 36% by weight of the water which is approximately saturated. Plug 1 reduced the salt content to 30% so that the strength of the grout would be greater while still providing good bonding to the salt formation. Fresh mix water (no dissolved salt) was used for plug 4 inside casing for maximum strength and to prevent chloride corrosion of the steel. Additives for plugs 1, 2, and 3 were calcium chloride (2%), salt gel (attpulgite, 2%), dispersant (0.1%)-- all percents by weight of cement plus flyash. Silica sand (5%) was included in the first three plugs to improve strength characteristics and to reduce circulation loss to the formation. The additives for plug 4 were 2% Bentonite gel and a fresh water turbulent inducer compound (friction reducer).

Dowell supplied the data in Table I. The grout slurries were tested at their Midland Laboratory for thickening time and strength gain in accordance with API RP10B "Testing Oil-Well Cements and Cement Additives" to simulate the downhole environment. The temperatures and confining pressures for each of the mixtures are listed in Table I. The salt-saturated mixture for plugs 2 and 3 had the longest thickening time of 7 hr, 45 min. The unconfined compressive strengths also show the effect of the salt in the mixtures. The plug 4 mixture had the highest strength at 72-hr age even though the curing temperature was significantly lower. The omission of 6% of the salt for plug 1 (30% instead of approximately fully saturated 36%) gave approximately a 50% strength increase at 72 hr for about the same temperature and confining pressure. These data confirmed the assumptions that were made in selecting the grout mixture designs for each plug.

Dowell Laboratory also worked with samples of the drilling mud to determine the appropriate type and amount of chemical wash to precede the grout. The chemical wash removes the circulatable mud from the hole and the casing surface to improve bonding and to serve as a buffer between the mud and the cement so that mud gelation does not occur. Dowell recommended the following amounts of salt saturated CW-100 fluid loss control mud flush:

Plug 1	2000 gal, 48 bbl
Plugs 2, 3	3500 gal, 83 bbl
Plug 4	1000 gal, 24 bbl

TABLE I

Grout Mixture Data

	Units	Plug 1* 30% Salt	Plugs 2, 3* 36% Salt	Plug 4* Fresh Water
Cement, Class C(SR)	lb/ft^3	42.90	39.58	54.83
Litepoz 3 (flyash)	lb/ft^3	14.47	13.35	18.50
Salt gel (Attapulgite)	lb/ft^3	1.15	1.06	-
Bentonite gel	lb/ft^3	-	-	1.47
Salt, D44	lb/ft^3	10.77	14.15	-
Silica sand, D44	lb/ft^3	3.26	3.01	-
Dispersant, D45	lb/ft^3	0.06	0.05	0.29
Dispersant, D65	lb/ft^3	-	-	-
Calcium chloride (S1)	lb/ft^3	1.15	1.06	-
Water	lb/ft^3	36.6	39.3	36.0
Density	lb/ft^3	108.5	107.0	112.2
Density	lb/gal	14.5	14.3	15.0
Yield	ft^3/sack	1.5	1.7	1.2
Water content	gal/sack	6.6	7.8	5.2
Water/cement ratio		0.85	0.99	0.66
Water/cement and flyash ratio		0.64	0.74	0.49
Thickening time	hr:min	4:35	7:45	5:05
Unconfined compressive strength				
24 hr	psi	712	426	1210
48 hr		1543	1032	1522
72 hr		1888	1275	2080

* Plug 1 cured at 128°F, 2445 psi
Plugs 2, 3 cured at 125°F, 2112 psi
Plug 4 cured at 80°F, 445 psi

All concerned agreed to the following operational procedures:

1. WES personnel will monitor the batching of dry materials at the Dowell plant in Artesia and will obtain samples of all materials.

2. WES will take a sample of the blended material from the tiers on the bulk trucks at the site.

3. After the 2-3/8 in. tubing is run in the hole and ready for cementing, the cement will be batch-mixed. WES will monitor the slurry density and take samples after the slurry is ready for pumping.

4. Saturated brine water and mud flush as determined above will precede the cement grout slurry.

5. The pumping rate is to be 3 to 4 bbl/min. Both the rate and pressure will be recorded.

6. After approximately two-thirds of the grout has been pumped into the plug location, the tubing will be raised about one-half the distance of the plug depth while maintaining at least 100 ft of grout above the bottom of the tubing.

7. Pumping will be continued until all of the grout has been pumped and displaced from the tubing or until uncontaminated grout appears at the surface. Where practicable, WES will obtain samples of both contaminated and uncontaminated grout returns.

8. The 2-3/8 in. tubing will be pulled.

9. The surface of the grout will be tagged after hardening before starting site operations for the next plug.

Plugging Operations

Plug 1

Plugging operations began at the site on October 1. The batching of materials for plug 1 was completed at the Dowell plant in Artesia on September 30. The operation of the batch plant was inspected by Sandia and WES personnel, and the calibration dates of the scales were noted. Samples of each of the following materials were obtained and later shipped to the WES Lab in Vicksburg for evaluation:

Class C (SR) INCOR cement
Litepoz 3 (flyash)
Attapulgite (brine gel)
D44 salt
D45 salt cement dispersant
D65 turbulent flow additive
S1 calcium chloride

The dry materials for plug 1 were weighed, blended, and loaded into the two tiers (tanks) of a bulk truck with dry materials for 207 ft^3 of grout slurry in each tier. The weighing operation was closely supervised, with the weight of each increment of material recorded by WES. After the blending process was completed a sample was taken for each tier. The batching operation was successful.

On-site preparations for plug 1 began early on October 1. The mixer was a twin tank, paddle mixing system with about 40 bbl, 224 ft^3 capacity in each tank. Some difficulty was encountered during the hookup and preliminary checkout of the system. Repairs and adjustments were satisfactorily completed by 11:00 a.m. Mixing of the grout then began with both the mix water and ambient air temperatures of 80°F. A sample of the dry material was taken from each tier of the bulk truck to check for any evidence of segregation during transport from the batch plant to the site.

With most of the fresh mix water in the tank, the dry materials were blown from the tiers on the bulk truck into the mixing tank by 10 to 15 psi air pressure. The slurry density was frequently checked by Dowell and WES after all the dry material had been added. The initial density was 14.9 lb/gal and was lowered to 14.7 lb/gal by the addition of water. At about 11:10 a.m. the slurry was pumpable, and the decision was made to use the grout slurry at this density rather than to add water to lower the mixture to the design density of 14.5 lb/gal. The second batch was mixed while batch 1 was being agitated in the tank. The initial slurry density was 15.1 lb/gal and could not be lowered below 14.9 lb/gal within the capacity of the mixing tank. This slurry was pumpable, and the decision was reached to pump batch number two into the hole first (thus becoming the grout at the top of the plug). The higher slurry density generally results in a higher strength.

The bottom of the tubing in the hole was just above the hole bottom 4431 ft deep. Starting at 11:45 a.m. Dowell pumped 10 bbl of brine water, 48 bbl of chemical mud flush and another 10 bbl of brine water at a pumping rate of 4 bbl/min. The grout slurry was then pumped at a rate of about 3 bbl/min at a line pressure of 1000 to 1250 psi. The pumping of all 414 ft^3 was finished by about 12:30 p.m. without any difficulty. The temperature of the grout slurry was 98°F at the beginning and 103°F at the completion of pumping.

WES cast cylinder specimens for observation and later shipment to the WES Laboratory for testing and evaluation. The cylinders were sealed and stored at the site and protected from the sun. At about 7-hr age, the samples from batch 1 were observed to have passed initial set, but not final set and had about the normal 1 to 2% bleed water at the surface. The samples from the batch 2 were hard to the touch (after final set), had no bleed water on the surface, and were warm from internal heat of hydration of the cement. These observations confirmed the higher fluid density (and lower water/cement ratio of batch 2) which resulted in a faster setting and hydration process. The ambient air temperature at the time of this observation was 90°F, and the peak air temperature had reached about 98°F during the afternoon.

The tubing had been removed from the hole after the completion of pumping, and the cement plug was allowed to harden for about 48 hr. The top of the hard material was tagged with the core barrel at a depth of 3556 ft. This indicated that little, if any, grout was lost to the formation. The 30% excess above hole size calculation filled an additional 25% extra hole depth. Also the higher than design density of the grout reduced the available grout volume by about 2%, and some grout was left in the mixing tanks.

Coring operations began at noon on October 3 (48-hr age of the grout) and were completed at midnight. A 50-ft core barrel with a core diameter of approximately 4 in. was used. Core 1 was drilled through the 39-ft interval from 3556 to 3595 ft with about 10 ft of recovered core mostly short pieces. Core 2 was drilled through the 28-ft interval from 3595 to 3623 ft with about 20 ft of recovered core with most pieces about 10 in. or longer. Core 3 was drilled through the 50-ft interval of 3623 to 3673 ft with about 28 ft of recovered core, with most pieces 8 in. or longer.

From the Dowell Laboratory data, the strength of the cement grout at 48-hr age should have been about 1543 psi for uncontaminated grout cured under the pressure of the column of drilling mud in the hole and at 128°F (Table 1). The core barrel was stuck at the end of each coring cycle which may have contributed to grinding and loss of some of the core. The core was immediately placed and sealed in plastic containers to prevent moisture loss during storage and shipment. The core pieces and surface cast samples were shipped to the WES Laboratory for testing and evaluation. Samples were also given to Dowell for testing in their laboratory at Tulsa.

Plug 2

The materials for plug 2 were batched and blended at the Artesia Dowell plant on Monday, October 1, under WES supervision. Because of the higher density for the cement slurry for plug 1, the bulk trucks were carefully inspected before loading. The lower portion of each of the tiers on each of the trucks was found to contain some cement. The normal cleaning operation at the yard apparently did not completely remove a small amount of the dry cement. All bulk trucks for this and subsequent plugs were carefully cleaned of all dry material before loading.

WES again supervised and recorded the weights of each material during the batching operations. Samples of the dry mixture from each of the four tiers were taken after blending and

loading before the trucks left the plant for the site. Three of the batches were 282 ft^3, and the fourth batch was 266 ft^3 for the total plug volume of 1112 ft^3 when mixed to the design slurry weight of 14.3 lb/gal.

On-site operations began early in the morning of October 3. Because of the operational problems with "lightning" batch mixers used on plug 1, the mixing equipment was changed for this and subsequent plugs. The grout slurry was mixed in the "tornado" mixer on the pump truck and pumped into a large horizontal cylinder tank with agitating blades. The tank capacity was 240 bbl, 1344 ft^3, enough for all of the slurry for each of the remaining plugs. A sample of the blended dry material from each tier was taken before mixing. Mixing started at 8:10 a.m. and was completed at 9:55 a.m. The uniform fluid density at the completion of mixing was 14.6 lb/gal. This was slightly above the design density 14.3 lb/gal and was pumpable. The weather was cool and raining during the grouting operations. Mix water temperature was 72°F, and the grout temperature was 88°F.

The tubing extended down to the top of the hardened grout (after coring) at a depth of 3673 ft. Pumping operations started at about 9:55 a.m. The 10 bbl of brine water was followed by 84 bbl of chemical mud flush, and another 10 bbl of brine water preceeded the grout. The brine and mud flush was pumped at a rate of 4 bbl/min and a line pressure of about 1000 psi. The grout slurry was pumped at an average rate of about 3.5 bbl/min and a line pressure of about 1000 psi for the first two-thirds of the plug volume. Pumping was stopped, and the tubing bottom was raised to 2953 ft. This depth should have placed the bottom of the tubing at least 100 ft below the grout/drilling mud in the hole. The remaining grout slurry was pumped at a rate of 3.6 bbl/min and a line pressure of 500 to 1100 psi. The grout slurry was displaced from the tubing, and the tubing bottom was raised to 2300 ft. Reversing out the top portion of the grout slurry was attempted by pumping drilling mud down the tubing. No grout was observed at the surface. The grouting operations were completed at 11:20 a.m.

The surface of the grout was later tagged at 2335 ft after a 12-hr wait to allow the cement to harden. During the pumping, the return of mud to the pit was noticeably less for a portion of the time, and several reductions of line pressure were noted on the pressure recorder. Approximately 30% of the grout slurry was lost to the formation. The increase in slurry weight resulted in a 2% volume decrease. After completing the pumping, approximately 10 bbl, 56 ft^3 or 5% of the total grout slurry in the agitating tank was below the suction line to the pump truck and had to be flushed out during cleanup. This loss in slurry volume of 7% was about equal to the reduction in plug length (and approximate volume) of 6%. Therefore, the planned 30% excess was not available to reverse out and clean off the top of the plug.

WES cast samples of the grout slurry during the pumping of the plug. The mixture appeared to be uniform, and all samples had hardened normally by the time that they were examined about 18 hr later. The normal 1% to 2% bleed was shown by the top surface of the hardened grout in each cylinder.

Plug 3

The materials for plug 3 were batched and blended during the late afternoon and evening of October 4 under WES supervision. Five tiers were loaded on a total of three batch trucks--four batches of 282 ft^3 and one batch of 201 ft^3. Samples of the dry mixture from each of the five tiers were taken after blending and loading.

On-site operations began the morning of October 5. The mixing and agitating tank equipment were the same as that used for plug 2. The mixing of the grout slurry started at 11:50 a.m. and was completed at 12:55 p.m. Ambient air temperature was 65°F, mix-water temperature was 69°F, and initial grout temperature into the tank was 84°F. After mixing 1329 ft^3, 237 bbls the slurry temperature was 89°F and the density was 14.7 lb/gal.

Pumping started at 12:45 p.m. with the tubing about 11 ft above the hardened surface of plug 2 at 2324 ft. The 10 bbl of brine water, 84 bbl of chemical mud flush, and 10 bbl of brine water were pumped downhole beginning about 12:45 p.m. at a rate of 4 bbl/min and completed at about 1:05 p.m. The first 155 bbl of grout slurry was pumped downhole at a rate of about 3.5 bbl/min and at a pressure of 500 to 1000 psi The tubing was then pulled to 1624 ft, and the remaining 82 bbl of grout was pumped at the same rate and with a line pressure of 300 to 500 psi. The grout was displaced from the tubing by pumping drilling mud down the tubing. The tubing was then raised to the bottom of the casing at 805 ft. The grout above that level was reverse-circulated out of the hole by pumping the drilling mud down the annulus and forcing the grout up the tubing. Samples of the grout return were obtained during the pumping of approximately 40 bbl, 224 ft^3 of cement grout and drilling mud. Pumping operations were completed at 2:40 p.m. About 8 hr later the hardened top of the grout was tagged at 826 ft.

WES cast the usual cylinder samples of grout taken from the agitating tank during the pumping of the plug. The samples exhibited a normal stiffening at about 10-hr age. Five of the six return sample specimens appeared to be relatively uncontaminated with drilling mud. The last specimen appeared to be mostly drilling mud with about 25% cement grout which had settled to the bottom.

Plug 4

Batching of dry materials for plug 4 was supervised by WES during the evening of October 5. One bulk truck was loaded with one tier containing 212 ft^3 and 204 ft^3. This provided about 20% above the calculated volume inside the casing to the surface.

Mixing truck and agitating tank remained in place because of the short time between clean-up and preparing for the next plug at 10 p.m. Mixing of the grout began at 11:35 p.m. Ambient air temperature was 50°F and the mix water temperature was 80°F. After mixing, the grout temperature was 90°F and the density was 14.9 lb/gal - slightly under the design density of 15.0 lb/gal. The bottom of the tubing was at 826 ft. Pumping of 10 bbl of brine water, 24 bbl of chemical mud flush, and 10 bbl of water ahead of the cement grout began at 12:10 a.m. on October 6 at a rate of about 4 bbl/min and a pressure of 300 psi. The first 10 bbl of grout was

pumped downhole at a rate of 3 bbl/min and the same pressure of 300 psi. Two joints of tubing were removed which raised the tubing to 766 ft for pumping the remainder of the plug. The final 64 bbl of grout was pumped at the rate of 3 bbl/min and the same pressure.

The uncontaminated grout did appear at the top of the casing. No samples of this return were taken because the grout ran to the bottom of the pit with drilling mud above. WES did cast the usual samples of grout taken from the agitating tank during pumping. Grouting operations were completed at 1 a.m.

The next day the level of grout had subsided about 16 ft below the top of the casing. This space was filled with a neat cement slurry.

General Comments and Conclusions

The samples remained at the site for at least 24 hr and were then moved to the Sandia office in Carlsbad. Testing of the core and surface samples from plug 1 was intended to begin as soon as possible at the WES laboratory in Vicksburg, Mississippi. Four cylinders and four boxes of core were shipped by air at 6-days age. The remainder of all samples and core were shipped by surface after the samples from plug 4 had reached 7-days age.

For plug 1 little, if any, grout was lost to the formation since the 30% excess grout filled about 25% extra hole. Also, the higher-than-design density reduced the available volume by about 2%. Most of the 30% excess grout for plug 2 was probably lost to the formation. The top of the plug 1 grout after coring was still 57 ft above the level used for estimating the volume and thereby reduced the planned volume by 4%. For plug 3, probably little grout was lost to the formation. The amount circulated out and the extra depth of hole to be filled just about equaled the 30% excess. The available excess grout for plug 4 was reduced to about 10% because of the outlet pipe location for the agitating tank which caused 6 to 10 bbl to remain in the tank. This was more severe for plug 4 because of the smaller plug volume. This feature pointed out another of the details which are important in the planning for a plugging operation.

The quality control procedures were adequate to provide a uniform cement slurry at the job site for pumping downhole into the plug locations. The cores recovered from plug 1 after only 24-hr curing showed that the grout in place hardened and gained strength similarly to the laboratory specimens tested under the temperature of 128°F and 2445 psi. There was no evidence of mud contamination in the hardened grout below the first core barrel depth of 50 ft. The surface cast specimens for all plug mixtures hardened through initial and final set within 12 hr as expected for the ambient air temperature conditions.

The operations at the batch plant were sampled and recorded to provide a data base for future borehole plugging operations. The data from the samples will be reported in subsequent reports as a part of the long term development and durability studies for the materials development and evaluation program.

References

1. Gulick, C. W., "Borehold Plugging - Materials Development Program", SAND78-0715, June 1978