



Project No. 78-245

July 80

**D'APPOLONIA**

**AD-A286 160**



**Report**

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**Results of Permeability Testing  
Rocky Mountain Arsenal**

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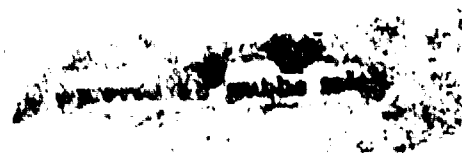
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**Testing Services**  
**Contract DAAK11-79-M-0003**

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U.S. Army Aberdeen Proving Ground  
APG(Edgewood), Maryland

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# Report

# Results of Permeability Testing Rocky Mountain Arsenal

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5	Qualitative Summary of Test Results

**Rocky Mountain Arsenal  
Information Center  
Commerce City, Colorado**

REPORT  
LONG-TERM PERMEABILITY TESTING  
UNITED STATES ARMY ABERDEEN PROVING GROUND  
CONTRACT DAAK11-79-M-0003

1.0 INTRODUCTION

In August, 1978 long-term permeability testing of soils and Basin F fluid from the Rocky Mountain Arsenal was undertaken by D'Appolonia Consulting Engineers (D'Appolonia). It was the purpose of the test program to measure, as a function of time, the permeability of cement-bentonite and various soil-bentonite mixes when acted upon by the Basin F fluid as a permeant. Initial testing was conducted for a 100-day period and was completed in December, 1978. This work was performed for the U. S. Army Waterways Experiment Station as Contract DACW39-78-M-3705. Continued testing of some of the initial samples and preparation of new samples was conducted for the U. S. Army Aberdeen Proving Ground as Contract DAAK11-79-M-0003. The second phase of testing was terminated in June, 1980. This report presents the complete test results for the samples tested through June, 1980.

During the initial 100-day period, twelve samples were tested. At the end of that test period samples 5 through 12 were discontinued and samples 1 through 4 were continued as part of the present contract. In addition, samples 13 through 16 were prepared and tested as part of this work. Thus, samples 1 through 4 have been tested for a period of 692 days and samples 13 through 16 for a period of 472 days.

Details concerning the soils and permeating fluid used in the test program are contained in the December, 1978 report issued by D'Appolonia for the contract with the Waterways Experiment Station and are not presented herein. However, for completeness it is noted that the permeating fluid was a mixture of 50% Basin F fluid and 50% distilled water, and the makeup of the samples tested are presented in Table 1. Identification numbers for the samples have remained unchanged throughout the entire test program.

## 2.0 PRESENTATION OF RESULTS

Contained herein are several tables and appendices which contain information pertinent to the test program. These are:

- Table 1 - a brief description of the samples tested.
- Table 2 - initial and final dimensions and weights of the test specimens.
- Table 3 - specific permeability calculations to illustrate the maximum difference in permeabilities computed using initial and final specimen dimensions.
- Table 4 - a summary of the averaged permeability values calculated for each sample during required reporting periods. It is noted that the values reported for the period ending June 30, 1980 are the average for the December 26, 1979 through June 30, 1980 period, and are not the average for the entire test period.
- Table 5 - a summary of the changes in permeability in comparison to initial values and duplicate samples.
- Appendix A - results of the permeability testing on a weekly basis for the entire test period.
- Appendix B - photographs of the samples after removal from the test equipment. Samples 1, 13, 14 and 15 were split longitudinally prior to photographing. Samples 2, 3, 4 and 16 were returned intact to the U. S. Army at their direction.

### 3.0 DISCUSSION OF RESULTS

In reviewing the test data several points should be considered:

- The reported permeability values have not been corrected for the changes in cross-sectional area and length which occurred during the test period. Table 3 demonstrates the effect of the maximum change in area and length upon resulting permeability values. Results for the maximum changes are small and within the accuracy of the test method. Therefore, these corrections have not been made. Also, it is noted that the actual change in length and diameter as a function of time is unknown so that if corrections were made the change as a function of time would have to be assumed, such as linearly varying during the test period. Should corrections be desired, the required information in Table 2 can be used.
- All permeabilities have been corrected to 20° C which is the standard temperature for reporting permeability values.
- Throughout the test period gas was generated within the test apparatus. To minimize the effect of the gas upon the test results, a release valve was provided in the system and the gas was vented at least once a week. This problem was discussed several times during testing with personnel of the Waterways Experiment Station and Aberdeen Proving Ground. The source of the gas is unknown, but it is felt that it was generated within the Basin F fluid, possibly due to contact with aluminum, brass or the polyethylene tubing in the test equipment. It is our understanding that the Waterways Experiment Station has had similar problems with gas generation.
- A new supply of Basin F fluid was provided to D'Appolonia in July, 1979 as an attempt to minimize gas generation. However, there was no noticeable reduction in gas generation.

- The effect of gas upon permeability was not evaluated as part of this work.
- Referring to Table 4, the measured permeability values have remained relatively unchanged throughout the test period. The most significant change is for Sample 1, which was a mixture of cement-bentonite. This sample has decreased permeability by an order of magnitude. All other samples, which are soil-bentonite mixes, have decreased in permeability by factors of four or less. This indicates that the Basin F fluid has not adversely affected the performance of the various mixes. The decrease in permeability is probably due to clogging of the samples by solids in the Basin F fluid.
- Table 5 presents a qualitative overview of the test results. The gross decrease in permeability is given along with the comparison of final permeability values in duplicate samples. The table shows that, with the exception of Sample 1, there was not a significant decrease in permeability for any of the samples. However, Sample 1 is a mix of cement-bentonite and as such may be more susceptible to clogging from solids suspended in the Basin F fluid because of its fine grained nature. Reviewing the results leads to several results:
  - permeabilities were not adversely affected during the test by Basin F fluid.
  - the test results are consistent because the duplicate samples resulted in the same final values except for one pair of samples which differed by a factor of two. However, in terms of permeability, a factor of two is not significant.
  - referring to the final column in Table 5 which shows a ratio of sample permeability to the most impermeable sample, the greatest variation is a factor of three. This is not significant in terms of permeability and indicates that the use of cement rather than soil or changing the percentage of -200 material does not greatly affect performance.

TABLES



TABLE 2  
INITIAL AND FINAL SPECIMEN MEASUREMENTS AND WEIGHTS

<u>Sample No.</u>	<u>Initial Avg. Diameter (cm)</u>	<u>Final Avg. Diameter (cm)</u>	<u>Initial Avg. Length (cm)</u>	<u>Final Avg. Length (cm)</u>	<u>Final Wet Weight (gms)</u>
1	7.29	6.80	13.08	11.58	531.5
2	7.29	6.94	14.38	13.21	933.7
3	7.29	6.94	11.81	11.02	877.3
4	7.29	6.92	11.76	11.30	872.9
13	7.29	6.48	13.84	12.12	824.6
14	7.29	6.72	12.70	11.00	816.8
15	7.29	6.27	11.43	10.31	680.1
16	7.29	6.72	14.22	10.26	754.2

TABLE 3  
PERMEABILITY CALCULATIONS

$$K_{20} = (0.93) \frac{QL}{T(h-x)A}$$

$K_{20}$  = permeability at temperature = 20°C, cm/sec

0.93 = correction factor for testing at 23°C

Q = total flow, cm<sup>3</sup>

L = length of flow path, cm

x = head adjustment for fluid in Burette, cm

A = cross-sectional area of flow, cm<sup>2</sup>

T = time, sec

h = head, cm

Maximum deviation from initial to final cross-sectional area

Sample 15 →  $A_i = 41.74 \text{ cm}^2$ ,  $A_f = 30.91 \text{ cm}^2$

Using  $A_i$

$$K_{20} = 0.93 \left[ \frac{(12.5)(11.43)}{(1303200)(220-7.2)(41.74)} \right] = 1.2 \times 10^{-8} \text{ cm/sec}$$

Using  $A_f$

$$K_{20} = 0.93 \left[ \frac{(12.5)(10.31)}{(1303200)(220-7.2)(30.91)} \right] = 1.4 \times 10^{-8} \text{ cm/sec}$$

↑  
INSIGNIFICANT  
↓

Maximum deviation from initial to final length

Sample 16 →  $L_i = 14.22 \text{ cm}$ ,  $L_f = 10.26 \text{ cm}$

Using  $L_i$

$$K_{20} = 0.93 \left[ \frac{(28.1)(14.22)}{(1303200)(220-16.0)(41.74)} \right] = 3.3 \times 10^{-8} \text{ cm/sec}$$

Using  $L_f$

$$K_{20} = 0.93 \left[ \frac{(28.1)(10.26)}{(1303200)(220-16.0)(35.47)} \right] = 2.8 \times 10^{-8} \text{ cm/sec}$$

↑  
INSIGNIFICANT  
↓

TABLE 4

AVERAGED PERMEABILITY VALUES FOR  
EACH REPORT PERIOD

Sample No.	through Nov. 16 '78*	Nov. 16 '78 through Apr. 2 '79	Apr. 2 '79 through June 29 '79	June 29 '79 through Dec. 26 '79	Dec. 26 '79 through June 30 '80
1	1.5 X 10 <sup>-7</sup>	1.9 X 10 <sup>-7</sup>	2.1 X 10 <sup>-8</sup>	3.6 X 10 <sup>-8</sup>	1.9 X 10 <sup>-8</sup>
2	8.0 X 10 <sup>-8</sup>	1.6 X 10 <sup>-7</sup>	6.4 X 10 <sup>-8</sup>	5.4 X 10 <sup>-8</sup>	2.0 X 10 <sup>-8</sup>
3	2.2 X 10 <sup>-8</sup>	2.9 X 10 <sup>-8</sup>	1.0 X 10 <sup>-8</sup>	6.8 X 10 <sup>-9</sup>	6.8 X 10 <sup>-9</sup>
4	1.3 X 10 <sup>-8</sup>	1.8 X 10 <sup>-8</sup>	1.3 X 10 <sup>-8</sup>	8.3 X 10 <sup>-9</sup>	9.3 X 10 <sup>-9</sup>
13	--	3.1 X 10 <sup>-8**</sup>	4.9 X 10 <sup>-8</sup>	3.6 X 10 <sup>-8</sup>	1.9 X 10 <sup>-8</sup>
14	--	2.8 X 10 <sup>-8**</sup>	1.9 X 10 <sup>-8</sup>	2.2 X 10 <sup>-8</sup>	1.2 X 10 <sup>-8</sup>
15	--	1.9 X 10 <sup>-8**</sup>	2.1 X 10 <sup>-8</sup>	2.6 X 10 <sup>-8</sup>	7.2 X 10 <sup>-9</sup>
16	--	3.3 X 10 <sup>-8**</sup>	4.0 X 10 <sup>-8</sup>	2.3 X 10 <sup>-8</sup>	1.7 X 10 <sup>-8</sup>

\*Results from initial 100-day test period

\*\*Test period March 16, 1979 through April 2, 1979

TABLE 5  
 QUALITATIVE SUMMARY OF TEST RESULTS

<u>Sample No.</u>	<u>Decrease in Permeability During Test</u>	<u>Duplicate Sample</u>	<u>Difference in Permeability of Duplicate Samples at end of Test</u>	<u>Approximate Ratio of Final Average Permeability to Sample 3**</u>
1	order of magnitude	NA	NA	3
2	factor of four	13	same	3
3	factor of two	14	factor of two	NA
4	less than factor of two	15	same	1.5
13	less than factor of two	2	same	3
14	less than factor of three	3	factor of two	2
15	less than factor of three	4	same	1
16	factor of two	12*	same	2.5

\*Sample 16 was the same soil-bentonite mix as sample 2 but the sample preparation was different. Sample 2 was mixed with distilled water. Sample 16 was mixed with a 1:15 dilution of the Basin F fluid with distilled water.

\*\*Sample 3 had the lowest permeability.

APPENDIX A  
RESULTS OF PERMEABILITY TESTING  
SAMPLES 1 THROUGH 4, 13 THROUGH 16

NOTES\*

1. Permeating fluid was 50% Basin F fluid and 50% distilled water.
2. Permeating fluid was distilled water. (Applied only to sample 12 of the initial testing program.)
3. Permeability values corrected for change in sample cross-sectional area and length due to consolidation of sample during test period.
4. Permeability values not corrected for change in cross-sectional area and length because test is continuing through report period.
5. Duplicate sample as indicated.
6. Permeability values not corrected at end of test period for change in cross-sectional area and length due to small effect on final results (see Table 3).

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\*The numbering and use of notes has been used throughout the test program. Therefore, some of the notes above are no longer applicable. Also, some of the notes were pertinent only to previous reporting periods.

Sample No. 1  
 Applicable Notes 1,4,6

Time (Days)	Permeability (cm/sec)
0-7	$4.8 \times 10^{-8}$
7-14	$9.7 \times 10^{-8}$
14-21	$1.3 \times 10^{-8}$
21-28	$2.0 \times 10^{-8}$
28-35	$2.0 \times 10^{-7}$
35-42	$2.4 \times 10^{-7}$
42-49	$1.5 \times 10^{-7}$
49-56	$2.0 \times 10^{-7}$
56-63	$6.3 \times 10^{-8}$
63-69	$2.4 \times 10^{-7}$
69-76	$2.6 \times 10^{-7}$
76-83	$1.8 \times 10^{-7}$
83-92	$1.4 \times 10^{-7}$
92-97	$2.3 \times 10^{-7}$
<u>97-100</u>	<u><math>1.7 \times 10^{-7}</math></u>
Average	$1.5 \times 10^{-7}$

Remarks - Permeant a light yellow color in burette.

Data from contract DACW39-78-M-3705

Sample No. 1Applicable Notes 1,4,6

Time (Days)	Permeability (cm/sec)
100-106	No flow*
106-114	$2.3 \times 10^{-7}$
114-119	$2.0 \times 10^{-7}$
119-125	$1.7 \times 10^{-7}$
125-133	$2.2 \times 10^{-7}$
133-140	$2.6 \times 10^{-7}$
140-148	$2.0 \times 10^{-7}$
148-157	$1.9 \times 10^{-7}$
157-163	$1.7 \times 10^{-7}$
163-170	$1.3 \times 10^{-7}$
170-178	$2.0 \times 10^{-7}$
178-189	$1.5 \times 10^{-7}$
189-199	$1.3 \times 10^{-7}$
199-209	$7.5 \times 10^{-8**}$
209-220	Clogged
220-224	$2.5 \times 10^{-9**}$
224-230	$2.0 \times 10^{-8**}$
<u>230-237</u>	<u><math>7.5 \times 10^{-9**}</math></u>
Average	$1.9 \times 10^{-7}$

\* No flow due to breakdown of Samples 5 through 12

\*\* Suspect data points, not included in average

Data from November 16, 1978 through April 2, 1979

Sample No. 1  
 Applicable Notes 1,4,6

Time (Days)	Permeability (cm/sec)
237-246	$5.9 \times 10^{-9}$
246-258	$4.5 \times 10^{-9}$
258-274	No Flow*
274-294	$1.7 \times 10^{-8}$
294-309	$7.7 \times 10^{-9}$
309-315	$9.9 \times 10^{-9}$
315-321	$8.4 \times 10^{-9}$
<u>321-325</u>	<u><math>9.7 \times 10^{-8}</math></u>
Average	$2.1 \times 10^{-8}$

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979

Sample No. 1  
Applicable Notes 1,4,6

Time (Days)	Permeability (cm/sec)
325-335	$1.1 \times 10^{-8}$
335-343	$2.1 \times 10^{-8}$
343-349	$2.7 \times 10^{-8}$
349-356	$1.4 \times 10^{-8}$
356-359	$1.0 \times 10^{-7}$
359-370	$1.2 \times 10^{-9}$
370-392	$1.8 \times 10^{-8}$
392-400	$9.3 \times 10^{-9}$
400-426	$3.8 \times 10^{-9}$
426-441	$1.1 \times 10^{-8}$
441-449	$1.5 \times 10^{-9}$
449-456	$1.3 \times 10^{-7}$
456-475	$3.4 \times 10^{-8}$
475-483	$1.0 \times 10^{-7}$
483-493	$5.2 \times 10^{-8}$
<u>493-505</u>	<u><math>3.6 \times 10^{-8}</math></u>
Average	$3.6 \times 10^{-8}$

Data from June 29, 1979 through December 26, 1979

Sample No. 1  
 Applicable Notes 1,4,6

Time (Days)	Permeability (cm/sec)
505-524	*
524-539	1.9 X 10 <sup>-8</sup>
539-548	1.4 X 10 <sup>-8</sup>
548-560	6.9 X 10 <sup>-8</sup>
560-573	4.3 X 10 <sup>-8</sup>
573-584	2.0 X 10 <sup>-8</sup>
584-597	No Flow
597-610	5.6 X 10 <sup>-9</sup>
610-619	8.6 X 10 <sup>-9</sup>
619-636	5.8 X 10 <sup>-9</sup>
636-647	8.3 X 10 <sup>-9</sup>
647-651	5.3 X 10 <sup>-9</sup>
651-661	4.0 X 10 <sup>-9</sup>
661-664	3.6 X 10 <sup>-8</sup>
664-678	5.1 X 10 <sup>-9</sup>
678-685	1.9 X 10 <sup>-8</sup>
685-692	1.5 X 10 <sup>-8</sup>
<hr/> Average	<hr/> 1.9 X 10 <sup>-8</sup>

Remarks - Bottom 3/4" of sample was discolored  
 possible clogging of porous stone  
 specimen very stiff  
 strong odor  
 effluent is greenish brown

\*No measured flow due to compressor problems during laboratory move to new facility.

Data from December 26, 1979 through June 30, 1980.

Sample No. 2  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
0-7	$1.3 \times 10^{-7}$
7-14	$7.2 \times 10^{-8}$
14-21	$5.1 \times 10^{-8}$
21-28	$4.1 \times 10^{-8}$
28-35	$4.3 \times 10^{-8}$
35-42	$1.0 \times 10^{-7}$
42-49	$7.8 \times 10^{-8}$
49-56	$7.4 \times 10^{-8}$
56-63	$4.1 \times 10^{-8}$
63-69	$9.2 \times 10^{-8}$
69-76	$1.4 \times 10^{-7}$
76-83	$9.3 \times 10^{-8}$
83-92	$8.2 \times 10^{-8}$
<u>92-100</u>	<u><math>8.3 \times 10^{-8}</math></u>
Average	$8.0 \times 10^{-8}$

Remarks - Duplicate to Samples 8 and 13. Permeant a dark amber color in burette.

Data from Contract DACW39-78-M-3705

Sample No. 2  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
100-106	No flow*
106-114	$1.4 \times 10^{-7}$
114-120	$1.5 \times 10^{-7}$
120-126	$1.8 \times 10^{-7}$
126-132	$1.7 \times 10^{-7}$
132-140	$2.2 \times 10^{-7}$
140-148	$2.0 \times 10^{-7}$
148-153	$2.3 \times 10^{-7}$
153-160	$2.3 \times 10^{-7}$
160-170	$5.9 \times 10^{-8**}$
170-178	$1.3 \times 10^{-7}$
178-183	$1.0 \times 10^{-7}$
183-189	$1.2 \times 10^{-7}$
189-199	$1.2 \times 10^{-7}$
199-209	$1.1 \times 10^{-7}$
209-220	$6.6 \times 10^{-8**}$
220-224	$9.8 \times 10^{-8**}$
224-230	Air Bubbles
<u>230-237</u>	<u><math>6.1 \times 10^{-8**}</math></u>
Average	$1.6 \times 10^{-7}$

Remarks - Duplicate to Samples 8 and 13

\* No flow due to breakdown of Samples 5 through 12

\*\* Suspect data points, not included in average

Data from November 16, 1978 through April 2, 1979

Sample No. 2  
 Applicable Notes 1,4,5,6

Time (Days)	Permability (cm/sec)
237-246	$5.5 \times 10^{-8}$
246-258	Leak
258-274	No Flow*
274-294	$3.6 \times 10^{-8}$
294-296	$6.4 \times 10^{-8}$
296-309	$6.3 \times 10^{-8}$
309-315	$7.6 \times 10^{-8}$
315-321	$6.5 \times 10^{-8}$
<u>321-325</u>	<u><math>9.1 \times 10^{-8}</math></u>
Average	$6.4 \times 10^{-8}$

Remarks - Duplicate to Samples 8 and 13

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979

Sample No. 2Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
325-335	$5.7 \times 10^{-8}$
335-343	$7.1 \times 10^{-8}$
343-349	$7.3 \times 10^{-8}$
349-356	$5.5 \times 10^{-8}$
356-359	$8.2 \times 10^{-8}$
359-370	$7.2 \times 10^{-8}$
370-381	$7.1 \times 10^{-8}$
381-392	$5.1 \times 10^{-8}$
392-400	$3.1 \times 10^{-8}$
400-426	$2.4 \times 10^{-8}$
426-441	$4.2 \times 10^{-8}$
441-449	$2.8 \times 10^{-8}$
449-468	$5.3 \times 10^{-8}$
468-483	$5.4 \times 10^{-8}$
483-493	No Flow*
<u>493-505</u>	<u><math>4.0 \times 10^{-8}</math></u>
Average	$5.4 \times 10^{-8}$

Remarks - Duplicate to Samples 8 and 13

\*No flow due to change of pressure lines to reduce air bubbles

Data from June 29, 1979 through December 26, 1979

INDIANAPOLIS

Sample No. 2  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
505-524	*
524-529	$1.5 \times 10^{-8}$
529-538	$2.7 \times 10^{-8}$
538-539	Changed Burette
539-548	$1.4 \times 10^{-8}$
548-560	$4.3 \times 10^{-8}$
560-573	$4.7 \times 10^{-8}$
573-584	$4.3 \times 10^{-8}$
584-597	$5.9 \times 10^{-9}$
597-610	$1.0 \times 10^{-8}$
610-619	$7.9 \times 10^{-9}$
619-636	$7.5 \times 10^{-9}$
636-647	$8.9 \times 10^{-9}$
647-651	$1.2 \times 10^{-8}$
651-661	$1.3 \times 10^{-8}$
661-664	$3.9 \times 10^{-8}$
664-678	$6.2 \times 10^{-9}$
678-685	$1.4 \times 10^{-8}$
685-692	$2.1 \times 10^{-8}$
Average	$2.0 \times 10^{-8}$

Remarks - Duplicate to Samples 8 and 13  
 bottom portion of sample slightly discolored  
 possible clogging of porous stone  
 strong odor  
 sample not split for closer observation  
 effluent is greenish brown

\*No measured flow due to compressor problems during laboratory move to new facility.

Data from December 26, 1979 through June 30, 1980.

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Sample No. 3Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
0-7	$3.9 \times 10^{-8}$
7-14	$2.4 \times 10^{-8}$
14-21	$1.2 \times 10^{-8}$
21-28	$5.1 \times 10^{-9}$
28-35	$1.6 \times 10^{-8}$
35-42	$2.8 \times 10^{-8}$
42-49	$2.1 \times 10^{-8}$
49-56	$2.0 \times 10^{-8}$
56-63	$7.4 \times 10^{-9}$
63-69	$2.1 \times 10^{-8}$
69-76	$4.0 \times 10^{-8}$
76-83	$2.4 \times 10^{-8}$
83-92	$2.2 \times 10^{-8}$
<u>92-100</u>	<u><math>2.4 \times 10^{-8}</math></u>
Average	$2.2 \times 10^{-8}$

Remarks - Duplicate to Samples 9 and 14. Permeant a light yellow color in burette.

Data from Contract DACW39-78-M-3705

Sample No. 3  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
100-106	No flow*
106-114	$3.8 \times 10^{-8}$
114-125	$3.8 \times 10^{-8}$
125-136	$4.6 \times 10^{-8}$
136-141	Clogged
141-157	$4.0 \times 10^{-8}$
157-163	$3.5 \times 10^{-8}$
163-170	$3.1 \times 10^{-8}$
170-178	$3.9 \times 10^{-8}$
178-189	$3.1 \times 10^{-8}$
189-199	$2.7 \times 10^{-8}$
199-209	$2.1 \times 10^{-8}$
209-220	$8.2 \times 10^{-9}$
220-224	Air Bubbles
224-230	$1.1 \times 10^{-8}$
<u>230-237</u>	<u><math>1.4 \times 10^{-8}</math></u>
Average	$2.9 \times 10^{-8}$

\* No flow due to breakdown of Samples 5 through 12

Data from November 16, 1978 through April 2, 1979

Sample No. 3  
 Applicable Notes 1,4,5,6

Time (Days)	Permability (cm/sec)
237-246	$7.9 \times 10^{-9}$
246-258	$7.5 \times 10^{-9}$
258-274	No Flow*
274-294	$1.0 \times 10^{-8}$
294-309	$8.9 \times 10^{-9}$
309-315	$1.5 \times 10^{-8}$
315-321	$4.8 \times 10^{-9}$
<u>321-325</u>	<u><math>1.9 \times 10^{-8}</math></u>
Average	$1.0 \times 10^{-8}$

Remarks - Duplicate to Samples 9 and 14

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979

INDIANAPOLIS

Sample No. 3  
Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
325-335	$1.8 \times 10^{-9}$
335-343	$7.2 \times 10^{-9}$
343-349	$1.0 \times 10^{-8}$
349-356	$7.0 \times 10^{-9}$
356-370	$6.3 \times 10^{-9}$
370-392	$9.3 \times 10^{-9}$
392-400	$4.5 \times 10^{-9}$
400-426	$6.1 \times 10^{-9}$
423-441	$5.5 \times 10^{-9}$
441-449	$5.3 \times 10^{-9}$
449-483	$9.7 \times 10^{-9}$
<u>483-493</u>	<u><math>9.3 \times 10^{-9}</math></u>
Average	$6.8 \times 10^{-9}$

Remarks - Duplicate to Samples 9 and 14

          
Data from June 29, 1979 through December 26, 1979

INDIANAPOLIS

Sample No. 3  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
493-505	*
505-524	$2.1 \times 10^{-9}$
524-539	$7.8 \times 10^{-9}$
539-548	$8.3 \times 10^{-9}$
548-560	$5.6 \times 10^{-9}$
560-573	$8.9 \times 10^{-9}$
573-584	$1.8 \times 10^{-9}$
584-597	$3.3 \times 10^{-9}$
597-610	$5.5 \times 10^{-9}$
610-619	$2.4 \times 10^{-9}$
619-636	$7.4 \times 10^{-9}$
636-647	$8.7 \times 10^{-9}$
647-651	$6.8 \times 10^{-9}$
651-661	$3.9 \times 10^{-9}$
661-664	$2.6 \times 10^{-8}$
664-678	$7.5 \times 10^{-9}$
678-685	$8.6 \times 10^{-10}$
685-692	$8.1 \times 10^{-9}$
<hr/> Average	<hr/> $6.8 \times 10^{-9}$

Remarks - Duplicate to Samples 9 and 14  
 top portion of sample discolored, including porous stone  
 bottom end of sample slightly discolored  
 strong odor  
 sample not split for closer observation  
 effluent is greenish brown

\*No measured flow due to compressor problems during laboratory  
 move to new facility.

Data from December 26, 1979 through June 30, 1980.

INDIANAPOLIS

Sample No. 4  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
0-7	$2.4 \times 10^{-8}$
7-14	$1.4 \times 10^{-8}$
14-21	$1.5 \times 10^{-8}$
21-28	$3.0 \times 10^{-9}$
28-35	$7.2 \times 10^{-9}$
35-42	$7.3 \times 10^{-9}$
42-49	$3.6 \times 10^{-9}$
49-56	$1.3 \times 10^{-8}$
56-63	$7.2 \times 10^{-9}$
63-69	$1.7 \times 10^{-8}$
69-76	$2.2 \times 10^{-8}$
76-83	$1.6 \times 10^{-8}$
83-92	$1.3 \times 10^{-8}$
<u>92-100</u>	<u><math>1.5 \times 10^{-8}</math></u>
Average	$1.3 \times 10^{-8}$

Remarks - Duplicate to Samples 10 and 15. As test period progressed, permeant fluid changed color from light yellow to black. Upon collection in burette, a clear fluid tends to appear in the top of the column as solids settle.

Data from Contract DACW39-78-M-3705

Sample No. 4  
 Applicable Notes 1, 4, 5, 6

Time (Days)	Permeability (cm/sec)
100-106	No flow*
106-114	$2.0 \times 10^{-8}$
114-125	$2.2 \times 10^{-8}$
125-136	$2.4 \times 10^{-8}$
136-141	Clogged
141-157	$1.6 \times 10^{-8}$
157-170	$1.6 \times 10^{-8}$
170-178	$2.3 \times 10^{-8}$
178-183	$1.9 \times 10^{-8}$
183-189	$1.7 \times 10^{-8}$
189-199	$1.7 \times 10^{-8}$
199-209	$1.1 \times 10^{-8}$
209-220	$9.4 \times 10^{-9}$
220-224	Air Bubbles
224-230	$1.2 \times 10^{-8}$
<u>230-237</u>	<u><math>1.7 \times 10^{-8}</math></u>
Average	$1.8 \times 10^{-8}$

Remarks - Duplicate to Samples 10 and 15

Data from November 16, 1978 through April 2, 1979

Sample No. 4  
 Applicable Notes 1,4,5,6

Time (Days)	Permability (cm/sec)
237-246	$1.3 \times 10^{-8}$
246-258	$7.3 \times 10^{-9}$
258-274	No Flow*
274-294	$9.1 \times 10^{-9}$
294-309	$1.1 \times 10^{-8}$
309-315	$1.5 \times 10^{-8}$
315-321	$9.0 \times 10^{-9}$
<u>321-325</u>	<u><math>2.4 \times 10^{-8}</math></u>
Average	$1.3 \times 10^{-8}$

Remarks - Duplicate to Samples 10 and 15

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979

INDIANAPOLIS

Sample No. 4Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
325-335	$8.6 \times 10^{-9}$
335-343	$1.0 \times 10^{-8}$
343-349	$8.6 \times 10^{-9}$
349-356	$1.0 \times 10^{-8}$
356-370	$8.0 \times 10^{-9}$
370-392	$9.9 \times 10^{-9}$
392-400	$9.5 \times 10^{-9}$
400-426	$6.2 \times 10^{-9}$
426-441	$8.3 \times 10^{-9}$
441-449	$3.4 \times 10^{-9}$
449-483	$8.5 \times 10^{-9}$
483-493	$6.9 \times 10^{-9}$
<u>493-505</u>	<u><math>9.5 \times 10^{-9}</math></u>
Average	$8.3 \times 10^{-9}$

Remarks - Duplicate to Samples 10 and 15

Data from June 29, 1979 through December 26, 1979

Sample No. 4  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
505-524	*
524-539	$9.1 \times 10^{-9}$
539-548	$1.7 \times 10^{-8}$
548-560	$1.1 \times 10^{-8}$
560-573	$1.2 \times 10^{-8}$
573-584	$1.1 \times 10^{-8}$
584-597	$4.6 \times 10^{-9}$
597-610	$6.3 \times 10^{-9}$
610-619	No Flow
619-636	$4.3 \times 10^{-9}$
636-647	$5.7 \times 10^{-9}$
647-651	$6.8 \times 10^{-9}$
651-661	$6.8 \times 10^{-9}$
661-664	$2.9 \times 10^{-8}$
664-678	$3.2 \times 10^{-9}$
678-685	$6.0 \times 10^{-9}$
685-692	$6.1 \times 10^{-9}$
<hr/> Average	<hr/> $9.3 \times 10^{-9}$

Remarks - Duplicate to Samples 10 and 15  
 top half of sample discolored in spots, including stone  
 bottom end of sample slightly discolored  
 strong odor  
 sample not split for closer observation  
 effluent is greenish brown

\*No measured flow due to compressor problems during laboratory  
 move to new facility.

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Data from December 26, 1979 through June 30, 1980.

Sample No. 13  
Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
0-4	$1.7 \times 10^{-8}$
4-10	$2.3 \times 10^{-8}$
<u>10-17</u>	<u><math>5.3 \times 10^{-8}</math></u>
Average	$3.1 \times 10^{-8}$

Remarks - Duplicate to Samples 2 and 8

Data from March 16, 1979 through April 2, 1979.

Sample No. 13  
 Applicable Notes 1,4,5,6

Time (Days)	Permability (cm/sec)
17-26	$5.4 \times 10^{-8}$
26-38	$3.2 \times 10^{-8}$
38-54	No Flow*
54-66	$4.4 \times 10^{-8}$
66-74	$4.3 \times 10^{-8}$
74-89	$4.5 \times 10^{-8}$
89-95	$5.0 \times 10^{-8}$
95-101	$5.4 \times 10^{-8}$
<u>101-105</u>	<u><math>6.9 \times 10^{-8}</math></u>
Average	$4.9 \times 10^{-8}$

Remarks - Duplicate to Samples 2 and 8

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979

INDIANAPOLIS



Sample No. 13Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
285-304	*
304-319	2.6 X 10 <sup>-8</sup>
319-328	3.6 X 10 <sup>-8</sup>
328-340	3.1 X 10 <sup>-8</sup>
340-353	3.6 X 10 <sup>-8</sup>
353-364	3.2 X 10 <sup>-8</sup>
364-377	8.4 X 10 <sup>-9</sup>
377-390	2.8 X 10 <sup>-8</sup>
390-399	6.1 X 10 <sup>-9</sup>
399-416	No Flow
416-427	7.5 X 10 <sup>-9</sup>
427-431	1.7 X 10 <sup>-8</sup>
431-441	4.8 X 10 <sup>-9</sup>
441-444	2.8 X 10 <sup>-8</sup>
444-458	4.2 X 10 <sup>-9</sup>
458-465	1.1 X 10 <sup>-8</sup>
465-472	1.1 X 10 <sup>-8</sup>
-----	-----
Average	1.9 X 10 <sup>-8</sup>

Remarks - Duplicate to Samples 2 and 8  
no discoloration of sample  
filter paper is black  
strong odor  
effluent is greenish brown

\*No measured flow due to compressor problems during laboratory  
move to new facility.

Data from December 26, 1979 through June 30, 1980.

Sample No. 14  
Applicable Notes 14,5,6

Time (Days)	Permeability (cm/sec)
0-4	$1.8 \times 10^{-8}$
4-10	$2.9 \times 10^{-8}$
<u>10-17</u>	<u><math>3.6 \times 10^{-8}</math></u>
Average	$2.8 \times 10^{-8}$

Remarks - Duplicate to Samples 3 and 9

Data from March 16, 1979 through April 2, 1979.

Sample No. 14Applicable Notes 1,4,5,6

Time (Days)	Permability (cm/sec)
17-26	$2.6 \times 10^{-8}$
26-38	$3.2 \times 10^{-9}$
38-54	No Flow*
54-74	$9.1 \times 10^{-9}$
74-89	$2.2 \times 10^{-8}$
89-95	$2.1 \times 10^{-8}$
95-101	$8.6 \times 10^{-9}$
<u>101-105</u>	<u><math>4.3 \times 10^{-8}</math></u>
Average	$1.9 \times 10^{-8}$

Remarks - Duplicate to Samples 3 and 9

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979.

Sample No. 14Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
105-115	$2.5 \times 10^{-8}$
115-122	No Flow*
122-123	$9.0 \times 10^{-8}$
123-129	$4.2 \times 10^{-8}$
129-136	$2.7 \times 10^{-8}$
136-139	$3.3 \times 10^{-8}$
139-150	$2.1 \times 10^{-9}$
150-172	$1.3 \times 10^{-8}$
172-180	$2.2 \times 10^{-8}$
180-206	$9.2 \times 10^{-9}$
206-221	$1.8 \times 10^{-8}$
221-229	$4.6 \times 10^{-10}$
229-263	$2.4 \times 10^{-9}$
263-273	$3.8 \times 10^{-9}$
<u>273-285</u>	<u><math>1.5 \times 10^{-8}</math></u>
Average	$2.2 \times 10^{-8}$

Remarks - Duplicate to Samples 3 and 9

\*No flow due to change of pressure lines to reduce air bubbles

Data from June 29, 1979 through December 26, 1979.

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Sample No. 14  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
285-304	*
304-319	$2.5 \times 10^{-8}$
319-328	$2.7 \times 10^{-8}$
328-340	$8.7 \times 10^{-9}$
340-353	$3.5 \times 10^{-9}$
353-364	No Flow
364-377	$1.7 \times 10^{-9}$
377-390	$4.8 \times 10^{-10}$
390-399	$1.6 \times 10^{-9}$
399-416	$2.1 \times 10^{-8}$
416-427	$4.8 \times 10^{-9}$
427-431	$1.8 \times 10^{-8}$
431-441	$4.7 \times 10^{-9}$
441-444	$3.8 \times 10^{-8}$
444-458	$4.4 \times 10^{-9}$
458-465	$9.7 \times 10^{-9}$
465-472	$8.0 \times 10^{-9}$
<hr/> Average	<hr/> $1.2 \times 10^{-8}$

Remarks - Duplicate to Samples 3 and 9  
 spotted discoloration throughout sample  
 top filter paper is black  
 strong odor  
 effluent is greenish brown

\*No measured flow due to compressor problems during laboratory  
 move to new facility.

Data from December 26, 1979 through June 30, 1980.

Sample No. 15Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
0-4	$1.6 \times 10^{-8}$
4-10	$2.1 \times 10^{-8}$
<u>10-17</u>	<u><math>2.1 \times 10^{-8}</math></u>
Average	$1.9 \times 10^{-8}$

Remarks - Duplicates to Samples 4 and 10

Data from March 16, 1979 through April 2, 1979.

Sample No. 15Applicable Notes 1,4,5,6

Time (Days)	Permability (cm/sec)
17-26	$1.4 \times 10^{-8}$
26-38	Clogged
38-54	No Flow*
54-74	$8.2 \times 10^{-9}$
74-89	$2.0 \times 10^{-8}$
89-95	$2.2 \times 10^{-8}$
95-101	$2.9 \times 10^{-8}$
<u>101-105</u>	<u><math>3.1 \times 10^{-8}</math></u>
Average	$2.1 \times 10^{-8}$

Remarks - Duplicate to Samples 4 and 10

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 29, 1979.

Sample No. 15Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
105-115	$2.0 \times 10^{-8}$
115-122	No Flow*
122-123	$2.0 \times 10^{-7}$
123-129	$1.1 \times 10^{-8}$
129-136	$1.6 \times 10^{-9}$
136-150	$5.2 \times 10^{-9}$
150-168	$1.7 \times 10^{-8}$
168-172	No Flow*
172-180	$1.9 \times 10^{-8}$
180-206	No Flow*
206-221	$5.9 \times 10^{-9}$
221-229	$6.9 \times 10^{-9}$
229-263	$1.2 \times 10^{-9}$
263-273	$6.8 \times 10^{-9}$
<u>273-285</u>	<u><math>1.6 \times 10^{-8}</math></u>
Average	$2.6 \times 10^{-8}$

Remarks - Duplicate to Samples 4 and 10

\*No flow due to change of pressure lines to reduce air bubbles

Data from June 29, 1979 through December 26, 1979.

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Sample No. 15  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
285-304	*
304-319	1.2 X 10 <sup>-8</sup>
319-328	1.5 X 10 <sup>-8</sup>
328-340	1.4 X 10 <sup>-8</sup>
340-353	No Flow
353-364	1.2 X 10 <sup>-9</sup>
364-377	No Flow
377-390	2.6 X 10 <sup>-9</sup>
390-399	4.5 X 10 <sup>-9</sup>
399-416	3.7 X 10 <sup>-9</sup>
416-427	6.9 X 10 <sup>-9</sup>
427-431	2.1 X 10 <sup>-9</sup>
431-441	4.7 X 10 <sup>-9</sup>
441-444	2.1 X 10 <sup>-8</sup>
444-458	4.3 X 10 <sup>-9</sup>
458-465	5.6 X 10 <sup>-9</sup>
465-472	3.1 X 10 <sup>-9</sup>
<hr/> Average	<hr/> 7.2 X 10 <sup>-9</sup>

Remarks - Duplicate to Samples 4 and 10  
 spotted discoloration near top portion of sample  
 top filter paper and stone is black  
 strong odor  
 effluent is greenish brown

\*No measured flow due to compressor problems during laboratory  
 move to new facility.

Data from December 26, 1979 through June 30, 1980.

Sample No. 16  
Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
0-4	$2.1 \times 10^{-8}$
4-10	$3.2 \times 10^{-8}$
<u>10-17</u>	<u><math>4.6 \times 10^{-8}</math></u>
Average	$3.3 \times 10^{-8}$

Remarks - Duplicate to Samples 5 and 11

Data from March 16, 1979 through April 2, 1979.

Sample No. 16  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
17-26	$5.1 \times 10^{-8}$
26-38	Leak
38-54	No Flow*
54-65	$1.8 \times 10^{-8}$
65-89	$1.7 \times 10^{-8}$
89-95	$5.3 \times 10^{-8}$
95-101	$3.0 \times 10^{-8}$
<u>101-105</u>	<u><math>7.1 \times 10^{-8}</math></u>
Average	$4.0 \times 10^{-8}$

Remarks - Duplicate to Samples 5 and 11

\*No flow due to change of pressure lines to reduce air bubbles

Data from April 2, 1979 through June 30, 1979.

Sample No. 16Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
105-115	$8.1 \times 10^{-9}$
115-122	No Flow*
122-123	$8.8 \times 10^{-8}$
123-129	$2.8 \times 10^{-9}$
129-136	$2.4 \times 10^{-9}$
136-150	$1.0 \times 10^{-8}$
150-161	$5.7 \times 10^{-8}$
161-172	$3.0 \times 10^{-8}$
172-180	$3.4 \times 10^{-8}$
180-206	$1.6 \times 10^{-8}$
206-221	$1.5 \times 10^{-8}$
221-229	$4.8 \times 10^{-9}$
229-263	$3.2 \times 10^{-9}$
263-273	$1.3 \times 10^{-8}$
<u>273-285</u>	<u><math>3.8 \times 10^{-8}</math></u>
Average	$2.3 \times 10^{-8}$

Remarks - Duplicate to Samples 5 and 11

\*No flow due to change of pressure lines to reduce air bubbles

Data from June 29, 1979 through December 26, 1979.

INDIANAPOLIS

Sample No. 16  
 Applicable Notes 1,4,5,6

Time (Days)	Permeability (cm/sec)
285-304	*
304-319	$3.3 \times 10^{-8}$
319-328	$3.5 \times 10^{-8}$
328-340	$9.1 \times 10^{-9}$
340-353	$7.9 \times 10^{-9}$
353-364	$2.9 \times 10^{-9}$
364-377	No Flow
377-390	No Flow
390-399	$1.0 \times 10^{-8}$
399-416	$1.3 \times 10^{-8}$
416-427	$1.4 \times 10^{-8}$
427-431	$1.4 \times 10^{-8}$
431-441	$1.0 \times 10^{-8}$
441-444	$5.0 \times 10^{-8}$
444-458	$4.1 \times 10^{-9}$
458-465	$1.5 \times 10^{-8}$
465-472	$1.4 \times 10^{-8}$
<hr/> Average	<hr/> $1.7 \times 10^{-8}$

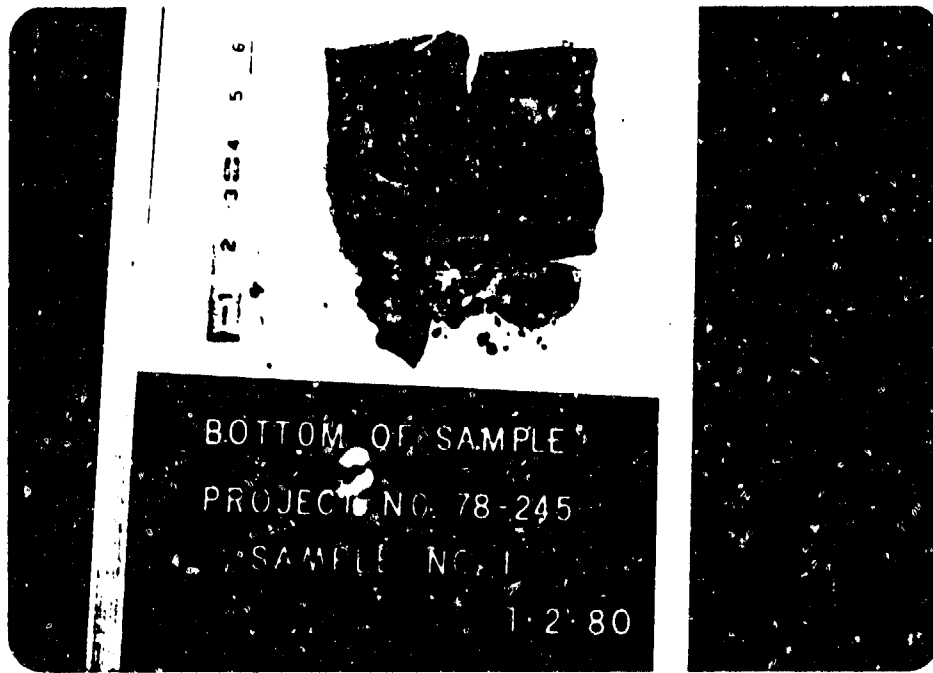
Remarks - Duplicate to Samples 5 and 11  
 top filter paper is black  
 bottom end of sample is dark brown  
 strong odor  
 effluent is greenish brown

\*No flow due to compressor problems during laboratory  
 move to new facility.

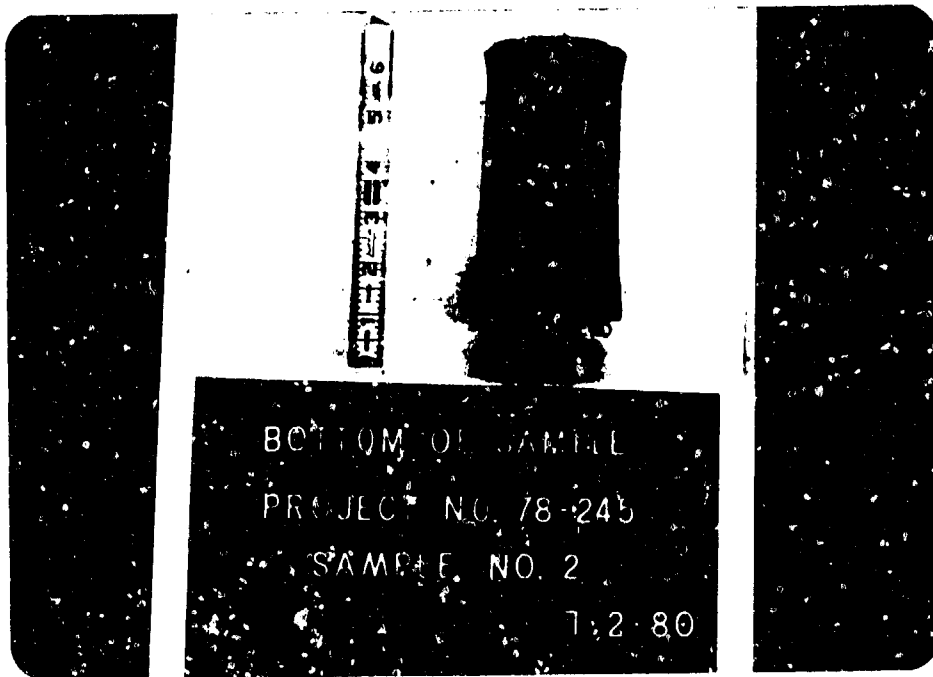
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Data from December 26, 1979 through June 30, 1980.

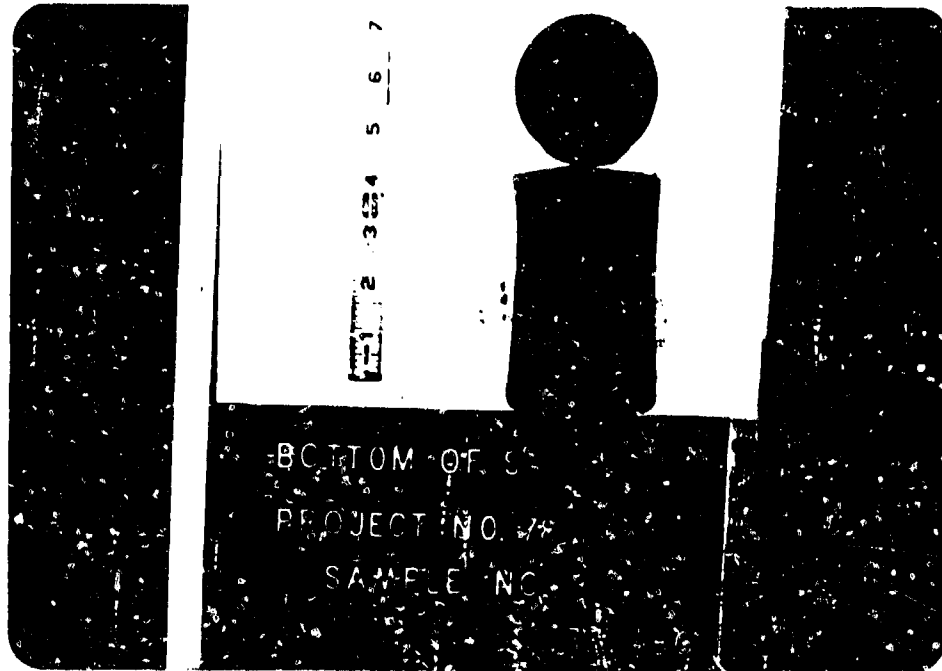
APPENDIX B  
PHOTOGRAPHS  
SAMPLES 1 THROUGH 4  
AND 13 THROUGH 16



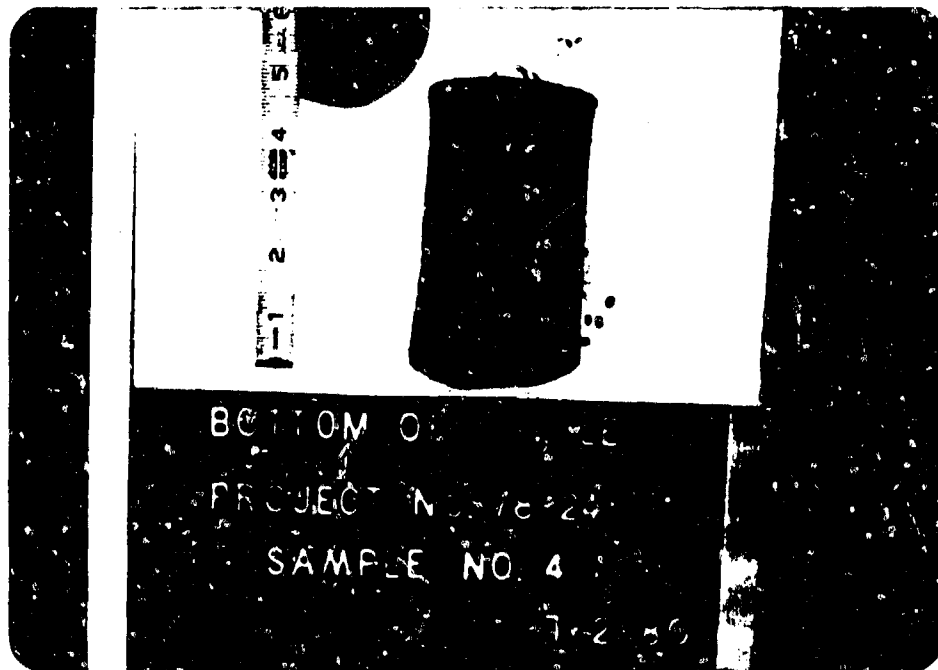
NOTE: Air bubbles in test sample are due to original mixing of sample.



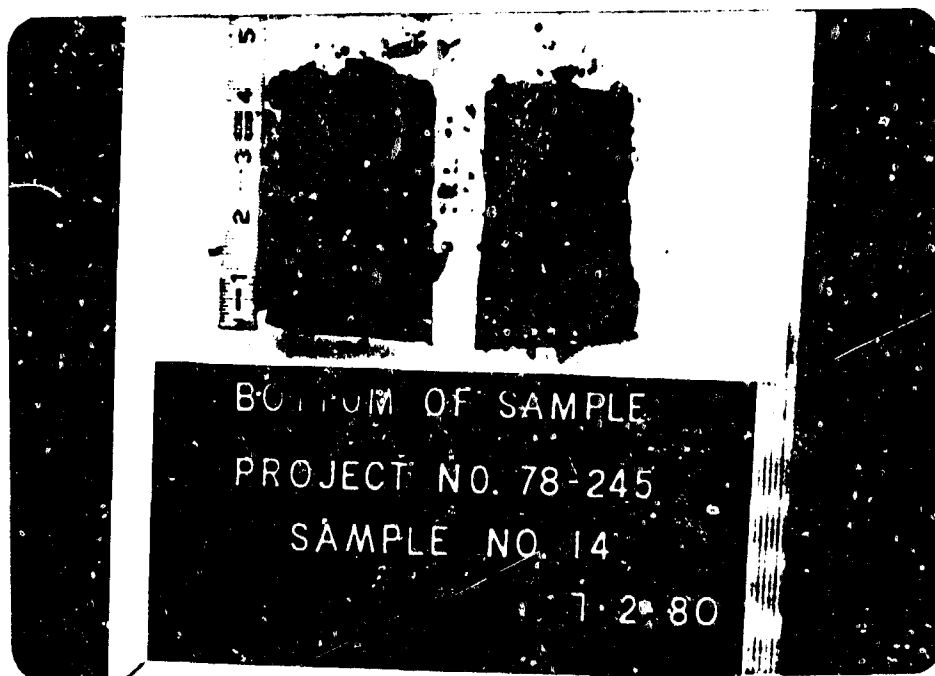
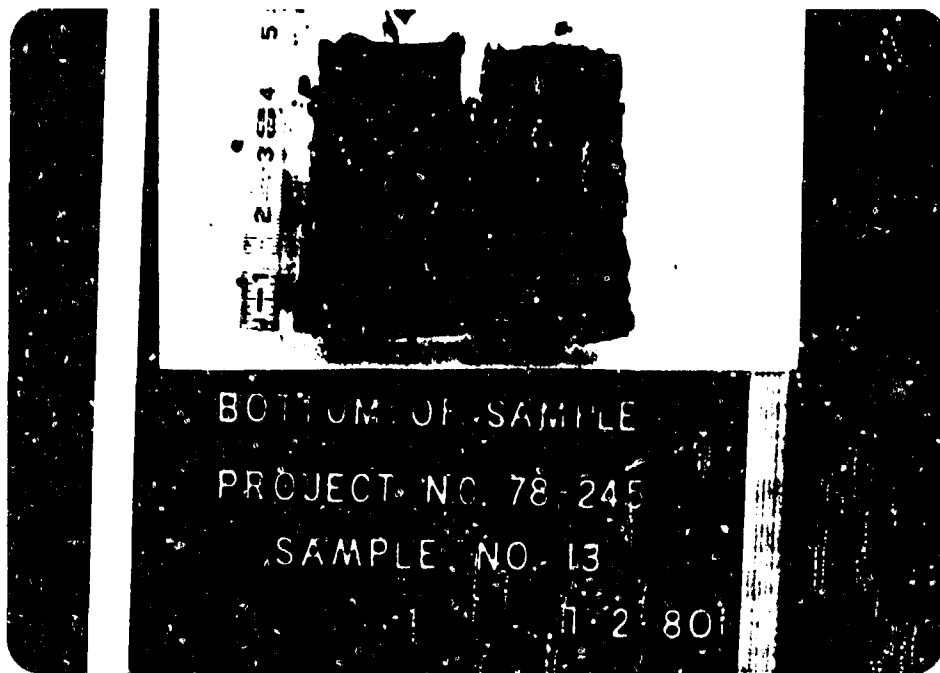
NOTE: Sample not split. Sent to Waterways Experiment Station for further testing.

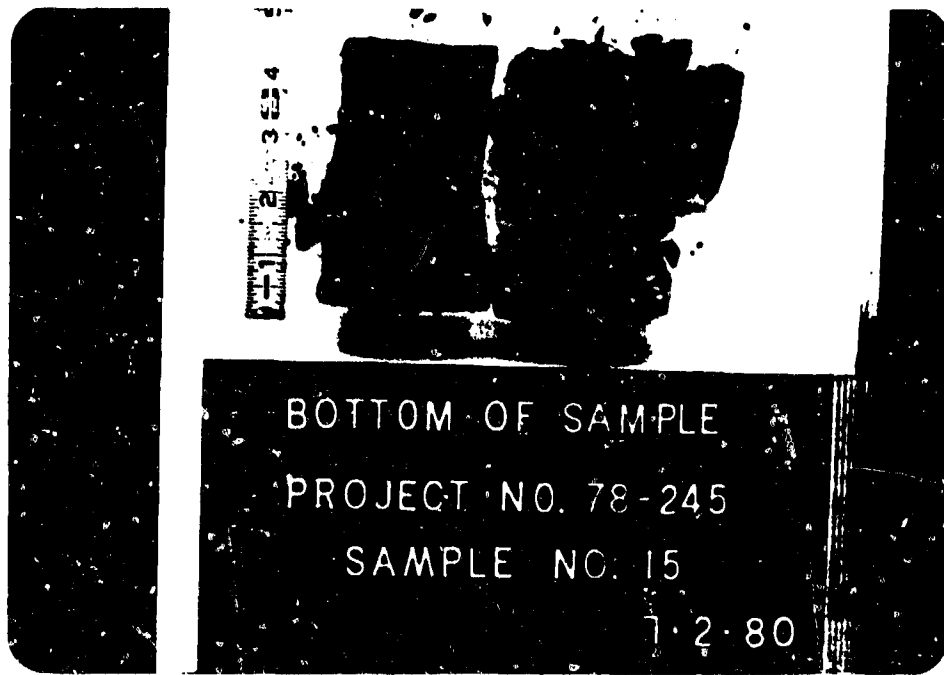


NOTE: Sample not split. Sent to Waterways Experiment Station for further testing.



NOTE: Sample not split. Sent to Waterways Experiment Station for further testing.





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