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A STUDY OF THE HOMOGENIZATION OF SOILS

by

**Luke R.S. Giovine
Forest L. Miller, Jr.**

June 1993

Publication #45102

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A STUDY OF THE HOMOGENIZATION OF SOILS

by

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prepared for

DOE Nevada Operations Office
U.S. Department of Energy
Las Vegas, Nevada

June 1993

The work upon which this report is based was supported by the U.S. Department of Energy under Contract #DE-AC08-90NV10845.

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ABSTRACT

In accordance with U.S. Environmental Protection Agency (U.S. EPA) regulations, areas of land that have been contaminated must be returned to an environmental condition that permits less restrictive forms of use. In anticipation of being listed as an EPA Superfund Site, the United States Department of Energy's (U.S. DOE) Nevada Test Site (NTS) is evaluating existing technologies, and supporting the development of new technologies, for the removal of plutonium contaminants from soils. During the 1950s, DOE conducted a series of tests on the NTS wherein attempts were made to detonate nuclear weapons by igniting charges of high explosives packed around the weapons' warheads. While the warheads never achieved criticality, each test disseminated particulate plutonium over several square miles, principally in Area 11 of the NTS. DOE's Nevada Operations Office (NVO) has committed to a Plutonium In Soils Integrated Demonstration Project (PuID) to evaluate existing and developmental technologies for the safe removal of plutonium contamination from soils. It is DOE's intention to provide approximately one ton of Area 11 soil, traced with a non-radioactive plutonium surrogate, to each of several companies with expertise in the removal of soil contaminants. These companies have expressed an interest in contracting with DOE for remediation of NTS soils. DOE wishes to evaluate each company's process in an unbiased and statistically justifiable manner. For this reason, DOE must provide to each company a large sample of soil for prototype testing. The soil must be homogenized such that the representativeness of each split is well documented and defensible. The process of uniformly mixing large volumes of soil has not been addressed, to our knowledge, in the hydrogeologic, soil science or mining literature. Several mixing devices are currently being evaluated by DOE for use in the PuID. This report describes the results of some initial experimentation with a small cement mixer. The experiments indicate that a soil's water content may be a crucial factor in determining the homogenization efficiency of a mixing process in a cement mixer. By analogy, we would expect a soil's water content to affect homogenization efficiencies in other mixers: such as pug mills, V-blenders, cone blenders, paddle mixers, ribbon blenders, and trommels. Additional studies are currently either being planned or performed with these mixers.

INTRODUCTION

Background

During the 1950s, the U.S. Department of Energy (DOE) conducted a series of tests on the Nevada Test Site (NTS), wherein attempts were made to detonate nuclear weapons by igniting charges of high explosives packed around the weapon's warheads. While the warheads never achieved criticality, the tests disseminated particulate plutonium over an area of approximately five square miles of Area 11 on the NTS. Similar tests were conducted by DOE on the Nellis Air Force Range (NAFR) and on the U.S. Air Force's Tonopah Test Range (TTR).

The dispersed plutonium is in particulate form. While originally scattered on the soil surface, natural processes such as precipitation have mobilized the plutonium. Some of the particles have penetrated the ground to varying depths (ranging to about 5 inches) while other particles have been transported by the wind. Historical records indicate that 10 safety shots were conducted, creating in excess of one million tons (20 million cubic feet) of soil with detectable plutonium (White et al., 1977). In accordance with regulations promulgated by the U.S. Environmental Protection Agency (EPA), areas of land that have been contaminated must be returned to an environmental condition that permits less restrictive forms of use. Historically, all of the plutonium contaminated areas on the NTS, NAFR, and TTR have been designated "as is" areas; while DOE recognized that the areas were contaminated, it did not consider the contamination to be an immediate hazard to the life and health of the general public because the areas were located on land subjected to restricted access. Subsequently, and in anticipation of being listed as an EPA Superfund Site, DOE has chosen to evaluate existing technologies, and support the development of new technologies, for the removal and minimization of plutonium contaminants from soils under its Plutonium In Soils Integrated Demonstration Project (PuID).

Project Goals

On the NTS, plutonium contamination exists over several square miles. Within the field of environmental remediation, there are no generally-accepted methods for stripping contaminated soils from large areas. Even if a practical stripping procedure could be developed, the volume of contaminated soil generated on the NTS is estimated to be in excess of 20 million cubic feet. Landfill disposal fees for such volumes are estimated to range into the several hundreds of millions of dollars. For this reason, DOE has chosen to subject the contaminated soil to some form of volume reduction process, with a goal of reducing the volume of contaminated materials by at least 75 percent. It is DOE's position that finding a means of concentrating the contaminants or, alternately, finding a means of separating the plutonium particles from the major portion of the soil, would enhance achieving a successful remediation.

The goal of the PuID is to evaluate the capabilities of various physical separation methods in removing plutonium particles from soils. While the focus of the project is the NTS, it is believed that most of the technology can be transferred to other DOE facilities. DOE-sponsored research at other locations is examining the use of non-physical separation processes for

removing radioactive contaminants from soils; the NTS facility is focusing on the evaluation of physical removal methods.

Physical Separation Methods

Previous research on the efficacy of physical separation as a method of volume reduction, such as the mineral jig system developed for use on Johnston Atoll, has indicated that such methods may be successful. Under the PuID, DOE is advocating a four-step approach to the problem:

- removing the contaminated soil from Area 11 to a location for physical separation of the plutonium,
- using a physical separation technique to remove the plutonium particles,
- disposing of the radioactive concentrate, and
- returning the decontaminated soil to the original site, to be followed by revegetation.

Previous experimentation involving physical separation processes has focused on screening out larger plutonium particles and scrubbing smaller plutonium particles off the surfaces of larger soil particles. This approach has reduced plutonium concentrations to between roughly one half and one third of the initial concentrations. Although no Federal standards have been set regarding allowable concentrations, it is believed that capabilities must be developed to reduce the concentrations below the levels of currently available technologies — perhaps as low as trace levels.

Soil Homogenization

It is DOE's intention to provide approximately one ton of Area 11 soil, traced with a non-radioactive plutonium surrogate, to each of several companies who have expressed an interest in contracting with DOE for remediation of the contaminated soils. At present, the mineral scheelite and bismuth metal are being considered as plutonium surrogates because of their similarities in specific gravity. DOE wishes to evaluate each vendor's process in an unbiased and statistically defensible manner. For this reason, DOE must provide to each vendor a large sample of soil for prototype testing. The soil must be homogenized in such a way that the representativeness of each split is well documented and defensible. The process of mixing large volumes of soil has not been addressed in the hydrogeologic or mining literature. Several mixing devices are currently being evaluated by DOE for use in the PuID. This report describes the results of some initial experimentation with a small cement mixer. The experiments indicate that a soil's water content may be a crucial factor in determining the homogenization efficiency of the mixing process in the cement mixer.

EXPERIMENTAL PROCEDURES

This research explored the mixing capabilities of a small cement mixer and the effect that water plays on the mixing process. The primary purpose of the experiment was to examine possible applications of cement mixers in preparing soil samples for the PuID. The experiment used a standard 2.5-cubic-foot cement mixer, as obtained from a local building supply retail store. The materials used in the experiment consisted of silica sand in various sizes (#12, #20, #30, and #60) and #9 lead shot. The lead shot, which has a nominal diameter of 0.08 inches, was intended to act as a plutonium surrogate with regard to its specific gravity. The lead shot is not expected to be representative of plutonium particles when mixing effects depend upon the particle size distribution of the plutonium.

The materials were placed into the cement mixer in varying amounts, with the axis of the cement mixer inclined at an angle of 22 degree above the horizontal. Then, the mixer was operated for a period of approximately 20 minutes. Coulson and Maitra (1950) investigated the effect of mixing time on dry solids in a rotary drum mixer inclined at various angles and operated at various speeds. They determined that an optimum mixing time exists, beyond which segregation or 'demixing,' in response to variations in particle size, occurs. The 20-minute time period was chosen empirically, based on the results of their work, after some initial experimentation with the cement mixer.

Samples were taken from 12 areas of the exposed surface within the mixer, as designated in Figure 1a. Each sample was dried and run through a series of sieves to determine the percentage of each particle size within the sample; particles of lead shot within the sample were individually counted. Each area was sampled to a depth of approximately 1 inch. Then, the upper four inches were removed and 12 areas of the newly exposed surface were sampled, again to a depth of one inch. This process was repeated until the mixer was emptied and resulted in sampling the contents of the mixer in four layers, for a total of 48 samples per experimental stage (Figure 1b). Water was added to the mixer at various stages of each experiment. However, the additions of water were not cumulative; the material was dried between experimental stages.

Three combinations of materials were used, in accordance with the following table:

Table 1. Sediment Fractions Used In Each Experiment

Experiment Number	Lead Shot (lbs.)	#12 Sand (lbs.)	#20 Sand (lbs.)	#30 Sand (lbs.)	#60 Sand (lbs.)
1	11	100	0	0	100
2	11	50	50	50	50
3	11	20	40	60	80

The particle distribution in the second experiment was chosen to see if increasing the number of particle sizes had a noticeable effect on the mixing process. In the final experiment,

Figure 1. Geometry of Sampling Areas and Layers Within the Mixer.

the distribution was chosen to mimic particle size distributions in natural soils. Each experiment was run three times: the first run contained no water, six liters of water were added to the mixture for the second run, and nine liters of water were added to the third run. All materials were dried between subsequent runs.

Data from the three experiments are presented in Appendix I, Tables 2 through 7. Sediment values are given as percentages of totals and lead shot values are piece counts. Particle distributions are plotted graphically in Figures 2 through 10. Each figure represents a different experimental stage and consists of four rows of five plots. The rows represent the layers in the mixer, with layer 1 being the topmost. The columns represent different particle size classifications. Within a given plot, the vertical axis is split into 10 divisions. Each division represents either 100 pieces of lead shot or 10 percent of the total sediment load. Axes in the horizontal plane divide the plot into the 12 sampling areas corresponding to those depicted in Figure 1a. The mouth of the mixer is positioned at the bottom right side of each plot; deeper into the mixer is aft and left. Only the raw data are plotted; no smoothing algorithm has been applied. The curvature of the mixer precluded materials from being distributed in Areas 1A and 1C in Layers 3 and 4; as a result, sediment percentages are shown as zero in the figures.

RESULTS

Experiment One

Without Water (Figure 2): A visible separation of materials occurred during the early portion of the first run. Sample analysis revealed that Area 1 consisted of 100% #12 sand with no trace of #60 sand or #9 lead shot. This segregation was uniform throughout the area and graded to roughly equal portions of the two sands in Area 2. Beyond Area 2, the percentage of #60 sand quickly increased and the fraction of #12 sand slowly decreased. In Area 4, the concentration of #12 sand declined to 8% and the fraction of #60 sand rose to 92%. The lead shot was absent in Area 1 and only trace amounts were found towards the rear section of Area 2. Seventeen percent of the shot was located Area 3 and 83% was found in Area 4. Segregation of the materials is clearly evident, implying that demixing has occurred.

With Six Liters of Water (Figure 3): A significant change was noted when water was added to the materials: the sands homogenized rapidly. The relative proportion of each sand remained fairly consistent from Area 1 through Area 4. Concentrations of the lead shot did exhibit changes — from 21% in Area 1 to 33% in Area 4 (mass percent).

With Nine Liters of Water (Figure 4): The 20-minute run with 9 liters of water produced the same trend as the 6-liter run, with indications of better mixing in Layer 4.

Experiment Two

Without Water (Figure 5): Strong segregation of the #12 sand occurred in Area 1, with no other materials being measurably present. Lead shot was absent in Areas 1 and 2. In Area 2, the

Figure 2: Experiment 1A; Dry Mixing

#30 Sand

#60 Sand

Figure 3: Experiment 1B; Six Liters of Water Added

#30 Sand

#60 Sand

Figure 4: Experiment 1C; Nine Liters of Water Added

#30 Sand

#60 Sand

Figure 5: Experiment 2A; Dry Mixing

#30 Sand

#60 Sand

various sand fractions become fairly equal. Area 3 shows the first substantial concentration of lead shot (18%). In Area 4, the #12, #20, and #30 sands share roughly 38% of the volume, with the #60 sand occupying 62% of the volume. Data for Layers 2 through 4 were not recorded in this run.

The data appear to show an anomalous elevation in the fraction of the #60 sand. Subsequent examination of the stock sands (as supplied by the vendor) indicated that the #20 and #30 sands contained a larger than expected fraction of #60 sand. We chose not to correct for this anomaly in order to employ a consistent procedure throughout the experiment. Eighty two percent of the lead shot was located in Area 4. In this experiment, the mixer appears to have distributed the materials in response to their angle of repose within the mixer.

With Six Liters of Water (Figure 6): With the introduction of water, the mixture appears to become relatively homogenized, with #60 sand showing a slight trend to increase its proportion with depth in the mixer. Only the lead shot shows a tendency to segregate as a result of the mixer's tilt. Nineteen percent of the shot was found in Area 1, increasing to 32% in Area 4. The sands exhibited nearly equal distribution throughout the four areas.

With Nine Liters of Water (Figure 7): Few differences were observed between the 6-liter and 9-liter experiments. However, the distribution of the #60 sand appears to have evened out with depth.

Experiment Three

Without Water (Figure 8): Significant segregation of materials was observed, with Area 1 containing 77% of the #12 sand. The lead shot was absent in Areas 1 and 2. In Area 2, the fraction of #12 sand decreased to 4%. In Area 3, there was a minimal amount of the #12 sand and 16% of the #9 lead shot appeared. In Area 4, the #12 sand was absent, the #60 sand reached a peak value of 73.7%, and 84% of the #9 lead shot was present.

With Six Liters of Water (Figure 9): With the introduction of water, the mixture of sediments approached homogeneity. Only the fraction of the lead shot varied across the mixer, increasing from 19% in Area 1 to 31% in Area 4.

With Nine Liters of Water (Figure 10): The final experiment followed the trend established in the 6-liter run, with a slight increase in homogeneity. The lead shot showed a more homogenized pattern, increasing from 23% in Area 1, to 27% in Area 4.

CONCLUSIONS

In the first stage of the first experiment (without water), the fractions of each sand member in a given sampling area appear to be influenced by their relative particle sizes. The lead shot, as a result of its higher density, is relegated to the back of the mixer. As shown in Figures 3 and 4, water appears to play an important role in the homogenization process. The viscous and/or

Figure 6: Experiment 2B; Six Liters of Water Added

#30 Sand

#60 Sand

Figure 7: Experiment 2C; Nine Liters of Water Added

#30 Sand

#60 Sand

Figure 8: Experiment 3A; Dry Mixing

1

#30 Sand

#60 Sand

Figure 9: Experiment 3B; Six Liters of Water Added

#30 Sand

#60 Sand

Figure 10: Experiment 3C; Nine Liters of Water Added

i

#30 Sand

#60 Sand

buoyancy effect of the liquid tends to override the effect of gravity on the different densities of the materials being mixed. It is postulated that the effect is due to a reduction of friction on the grain surfaces. Further experimentation is planned to explore this theory.

In the second experiment, the distribution of particles in the mixer appears to have been controlled by two factors: (1) the angle of repose of the particles, and (2) the moisture content of the mixture. Of these two factors, the moisture content appears to be dominant. Regrettably, the moisture content of each sample was not measured and conclusions stated herein assume that the water was uniformly distributed throughout the mixer. As this may not be the case, distribution of moisture content will be addressed in a subsequent series of experiments. Qualitatively, it appears that once a critical water content has been reached, additional water appears to exert minimal effects on the distribution of the particles. In these experiments, the critical water content appears to be less than 6 liters, which equates to roughly 6% by weight. We can also state that the critical water content is not sharply defined, as additional water (up to 9 liters) appears to give some additional benefit to the mixing process.

Experiment 3 exhibited the same trend as established in experiments 1 and 2. However, there was a greater change in the distribution of the lead shot particles (towards increasing homogenization) between the 6- and 9-liter runs as the distribution of sand particles became wider. As the percentage of small particles (#60 sand) increases, the total surface area of the sediments increases. This, in turn, requires that additional water be added to wet the available surface area. We postulate that as the percentage of small particles increases, additional water must be added to develop the critical water content at which homogenization ensues. A subsequent series of experiments is planned to investigate this process in more quantitative detail.

SUMMARY

The principal objective of these experiments was to investigate the mixing capabilities of a batch, rotary drum or 'cement' mixer. A secondary objective was to investigate the effects of water on the mixing process. The results of the experiment indicate that:

- 1) the density and grain size of a material influences the position that it will occupy inside a mixer while the mixer is operating. Although the #12 sand particles and the #9 lead shot are approximately the same size, they distribute themselves differently in the mixer, indicating that particle density plays an effect in mixing. Similarly, differences in grain distribution patterns were observed in the second experiment, indicating that particle size also plays a role;

- 2) when a certain critical volume of water is introduced into the mixture, the effect of density separation is greatly diminished;

- 3) once a critical moisture content is reached, the addition of more water appears to have a minimal effect on the distribution of particles in the mixer. In these experiments, the critical

water content appears to be less than 6 liters (6% of the total mixture, by weight). In the third experiment, the addition of extra water appears to have influenced the distribution of the lead shot. It is postulated that as the percentage of small particles increases, the corresponding increase in total surface area requires that additional water be added to develop the critical water content at which homogenization is optimized. Qualitatively, we believe that the cement mixer adequately mixed the soils and lead shot once a critical moisture content was achieved. However, the initial approach needs to be explored in quantitative detail. A second series of experiments is currently being designed to determine the value of a soil mixture's critical moisture content as a function of sediment particle size distribution and particle density. These experiments will also measure variations in the sediment's moisture content as a function of position within the mixer, and will investigate the effects of mixing times. A third series of experiments is planned to investigate the effects of mixer geometry; a V-blender, a paddle mill, a ribbon blender and, perhaps, a pug mill will be used. In all subsequent experiments, statistical tools will be used to quantify the degree of homogeneity, rather than relying on qualitative examinations of sediment distribution patterns. The use of statistical tools to determine mixing efficiency is not all that well accepted in the process engineering literature. The reasons for this will need to be explored.

This and future experiments are being conducted to enhance mixing of large volumes of soils on the PuID. Moreover, mixing will be able to be achieved with a minimum addition of water. Minimizing water use is important on the PuID, not only for conservation purposes but, also to minimize the generation of contaminated water which will require subsequent treatment.

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APPENDIX A

EXPERIMENTAL DATA

TABLE 2. PARTICLE FRACTIONS; EXPERIMENT 1, LAYERS 1 AND 2.

100 lbs #12 sand + 100 lbs #60 sand + 11 lbs #9 lead shot															
Areas	Mixture with no water added					Mixture with 6 liters of water added					Mixture with 9 liters of water added				
	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand
Layer 1															
1-A	0	100	--	--	0	30	53	--	--	47	50	52	--	--	48
B	0	100	--	--	0	32	50	--	--	50	47	49	--	--	51
C	0	100	--	--	0	28	48	--	--	52	24	50	--	--	50
2-A	18	30	--	--	70	32	50	--	--	50	70	50	--	--	50
B	0	29	--	--	71	32	50	--	--	50	61	50	--	--	50
C	2	20	--	--	80	26	50	--	--	50	40	50	--	--	50
3-A	29	13	--	--	87	46	50	--	--	50	57	50	--	--	50
B	67	11	--	--	89	43	47	--	--	53	32	51	--	--	49
C	8	12	--	--	88	42	50	--	--	50	42	51	--	--	49
4-A	7	12	--	--	88	26	46	--	--	54	48	44	--	--	56
B	766	7	--	--	93	30	50	--	--	50	58	45	--	--	55
C	727	7	--	--	93	49	50	--	--	50	56	42	--	--	58
Layer 2															
1-A	1	47	--	--	53	36	47	--	--	53	47	51	--	--	49
B	1	49	--	--	51	37	48	--	--	52	40	50	--	--	50
C	0	44	--	--	46	38	50	--	--	50	34	51	--	--	49
2-A	5	13	--	--	87	41	50	--	--	50	46	51	--	--	49
B	15	19	--	--	81	25	48	--	--	52	27	50	--	--	50
C	17	17	--	--	83	36	50	--	--	50	47	50	--	--	50
3-A	94	10	--	--	90	25	48	--	--	52	44	50	--	--	50
B	133	15	--	--	85	35	52	--	--	48	58	50	--	--	50
C	107	10	--	--	90	57	48	--	--	52	60	50	--	--	50
4-A	661	7	--	--	93	30	50	--	--	50	60	47	--	--	53
B	818	5	--	--	95	37	52	--	--	48	54	43	--	--	57
C	701	7	--	--	93	31	52	--	--	48	40	50	--	--	50

TABLE 3. PARTICLE FRACTIONS; EXPERIMENT 1, LAYERS 3 AND 4.

100 lbs #12 sand + 100 lbs #60 sand + 11 lbs #9 lead shot															
Areas	Mixture with no water added					Mixture with 6 liters of water added					Mixture with 9 liters of water added				
	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand
Layer 3															
1-A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	0	57	--	--	43	33	51	--	--	49	68	48	--	--	52
C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-A	6	16	--	--	84	30	52	--	--	48	58	50	--	--	50
B	26	18	--	--	82	25	50	--	--	50	54	49	--	--	51
C	4	12	--	--	88	44	51	--	--	49	38	50	--	--	50
3-A	127	11	--	--	89	62	58	--	--	42	68	52	--	--	48
B	299	10	--	--	90	16	59	--	--	41	46	50	--	--	50
C	417	11	--	--	89	47	53	--	--	47	61	50	--	--	50
4-A	883	5	--	--	95	20	62	--	--	38	52	49	--	--	51
B	682	6	--	--	94	1	62	--	--	38	74	47	--	--	53
C	667	7	--	--	93	59	53	--	--	47	72	49	--	--	51
Layer 4															
1-A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	15	21	--	--	79	33	51	--	--	49	85	46	--	--	54
C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-A	1	15	--	--	85	34	48	--	--	52	42	49	--	--	51
B	10	15	--	--	85	43	50	--	--	50	26	50	--	--	50
C	1	15	--	--	85	39	50	--	--	50	52	49	--	--	51
3-A	58	10	--	--	90	34	42	--	--	58	74	49	--	--	51
B	74	12	--	--	88	19	82	--	--	18	71	53	--	--	47
C	71	11	--	--	89	31	50	--	--	50	54	46	--	--	54
4-A	534	7	--	--	93	14	69	--	--	31	88	48	--	--	52
B	603	6	--	--	94	0	66	--	--	34	46	55	--	--	45
C	522	9	--	--	91	45	51	--	--	49	41	50	--	--	50

TABLE 4. PARTICLE FRACTIONS; EXPERIMENT 2, LAYERS 1 AND 2.

50 lbs #12 sand + 50 lbs #20 sand + 50 lbs #30 sand + 50 lbs #60 sand + 11 lbs #9 lead shot															
	Mixture with no water added					Mixture with 6 liters of water added					Mixture with 9 liters of water added				
Areas	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand
Layer 1															
1-A	0	100	0	0	0	35	37	20	17	26	24	24	18	20	38
B	0	100	0	0	0	22	36	20	16	28	26	24	20	15	41
C	0	100	0	0	0	34	37	20	14	29	27	23	15	21	41
2-A	0	30	25	23	22	30	32	19	24	25	31	21	17	21	41
B	0	23	28	21	28	24	33	20	16	31	32	22	15	24	39
C	0	16	32	13	39	34	40	16	16	28	46	24	14	19	43
3-A	126	8	11	20	61	48	37	20	16	27	36	22	14	22	42
B	74	8	13	25	54	59	40	20	13	27	38	22	12	22	44
C	14	10	11	18	61	31	38	19	15	27	43	22	13	23	42
4-A	180	9	12	18	61	52	37	18	16	29	66	21	15	22	42
B	134	5	11	18	66	54	38	20	15	27	29	20	14	26	40
C	230	8	13	19	60	44	41	18	15	26	45	23	15	21	41
Layer 2															
1-A	--	--	--	--	--	34	21	17	21	41	57	24	21	17	38
B	--	--	--	--	--	55	27	16	18	39	49	23	18	21	38
C	--	--	--	--	--	27	27	16	19	38	34	22	21	21	35
2-A	--	--	--	--	--	60	27	17	17	39	52	20	21	23	36
B	--	--	--	--	--	53	27	17	18	38	49	24	21	19	36
C	--	--	--	--	--	55	26	14	20	40	47	25	23	17	35
3-A	--	--	--	--	--	37	26	14	21	39	46	23	20	20	37
B	--	--	--	--	--	100	33	14	18	35	52	24	18	21	37
C	--	--	--	--	--	50	25	14	19	42	53	23	20	18	39
4-A	--	--	--	--	--	171	16	10	18	56	45	21	20	19	40
B	--	--	--	--	--	34	13	13	23	51	65	24	21	19	36
C	--	--	--	--	--	49	12	12	21	55	56	23	21	21	35

TABLE 5. PARTICLE FRACTIONS; EXPERIMENT 2, LAYERS 3 AND 4.

50 lbs #12 sand + 50 lbs #20 sand + 50 lbs #30 sand + 50 lbs #60 sand + 11 lbs #9 lead shot															
Areas	Mixture with no water added					Mixture with 6 liters of water added					Mixture with 9 liters of water added				
	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand
Layer 3															
1-A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	59	28	19	16	37	53	21	26	19	34
C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-A	--	--	--	--	--	41	26	14	22	38	49	24	23	18	35
B	--	--	--	--	--	60	26	14	20	40	44	23	23	18	36
C	--	--	--	--	--	54	25	15	21	38	59	23	23	18	36
3-A	--	--	--	--	--	52	25	14	19	42	79	23	23	18	36
B	--	--	--	--	--	86	22	17	19	41	67	22	17	22	39
C	--	--	--	--	--	61	27	13	20	40	54	23	22	18	37
4-A	--	--	--	--	--	51	18	19	19	44	62	21	20	20	39
B	--	--	--	--	--	10	18	29	21	32	69	24	19	19	38
C	--	--	--	--	--	11	18	13	20	49	58	23	19	19	39
Layer 4															
1-A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	45	25	14	21	40	35	19	24	19	38
C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-A	--	--	--	--	--	44	27	16	19	38	42	23	23	17	37
B	--	--	--	--	--	52	27	16	19	38	51	23	22	20	35
C	--	--	--	--	--	65	26	15	21	38	44	24	21	18	37
3-A	--	--	--	--	--	46	26	15	21	38	57	23	26	15	36
B	--	--	--	--	--	47	26	15	18	41	59	25	24	16	35
C	--	--	--	--	--	66	26	13	20	41	41	23	19	23	35
4-A	--	--	--	--	--	51	23	15	20	42	58	24	20	20	36
B	--	--	--	--	--	1	7	13	47	33	58	18	26	20	36
C	--	--	--	--	--	63	24	15	22	39	61	25	22	18	35

TABLE 6. PARTICLE FRACTIONS; EXPERIMENT 3, LAYERS 1 AND 2.

20 lbs #12 sand + 40 lbs #20 sand + 60 lbs #30 sand + 80 lbs #60 sand + 11 lbs #9 lead shot															
	Mixture with no water added					Mixture with 6 liters of water added					Mixture with 9 liters of water added				
Areas	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand
Layer 1															
1-A	0	67	24	9	0	52	10	14	24	52	50	10	14	24	52
B	0	88	9	3	0	55	13	17	20	50	43	11	17	22	50
C	0	72	23	5	0	37	13	15	23	49	51	12	18	20	50
2-A	0	5	45	42	8	55	11	16	24	49	41	11	14	25	50
B	0	5	32	44	19	48	11	12	23	54	40	12	15	24	49
C	0	8	47	38	7	47	12	15	26	47	50	13	16	21	50
3-A	0	2	11	21	66	51	10	16	24	50	53	11	17	22	50
B	2	0	17	20	63	62	14	19	19	48	54	12	14	23	51
C	1	0	9	26	65	42	12	18	18	52	45	11	14	24	51
4-A	170	0	5	19	76	55	10	13	22	55	49	11	14	23	52
B	444	0	7	17	76	39	13	16	19	52	16	5	10	18	67
C	251	0	7	19	74	42	11	21	18	50	62	11	14	24	51
Layer 2															
1-A	--	--	--	--	--	41	11	17	22	50	47	10	15	23	52
B	--	--	--	--	--	57	15	17	21	47	51	9	15	22	54
C	--	--	--	--	--	43	13	17	20	50	51	11	15	23	51
2-A	--	--	--	--	--	48	11	14	22	53	54	12	13	24	51
B	--	--	--	--	--	54	10	17	21	52	42	9	16	23	52
C	--	--	--	--	--	61	11	19	19	51	53	9	13	25	53
3-A	--	--	--	--	--	44	11	14	22	53	56	8	15	23	54
B	--	--	--	--	--	54	12	15	23	50	62	12	13	23	52
C	--	--	--	--	--	71	13	14	21	52	54	11	14	25	50
4-A	--	--	--	--	--	50	14	14	22	50	61	12	14	22	52
B	--	--	--	--	--	72	12	13	17	58	55	11	15	21	53
C	--	--	--	--	--	53	10	16	19	55	47	10	12	24	54

TABLE 7. PARTICLE FRACTIONS; EXPERIMENT 3, LAYERS 3 AND 4.

20 lbs #12 sand + 40 lbs #20 sand + 60 lbs #30 sand + 80 lbs #60 sand + 11 lbs #9 lead shot															
	Mixture with no water added					Mixture with 6 liters of water added					Mixture with 9 liters of water added				
Areas	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand	#9 Shot	#12 Sand	#20 Sand	#30 Sand	#60 Sand
Layer 3															
1-A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	0	80	12	7	1	33	12	17	20	51	37	11	13	24	52
C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-A	0	2	15	28	55	57	12	16	21	51	50	11	14	24	51
B	1	2	18	32	48	50	12	18	20	50	57	10	15	25	50
C	0	2	21	40	37	47	11	19	21	49	41	10	14	24	52
3-A	206	0	5	18	77	58	13	15	23	49	60	9	14	24	53
B	70	3	10	21	67	53	11	16	24	49	65	11	16	22	51
C	2	2	9	24	65	45	12	14	23	51	48	10	15	23	52
4-A	314	0	6	22	72	58	13	15	21	51	45	9	16	22	53
B	146	0	8	23	69	63	6	12	20	62	54	10	14	23	53
C	165	0	7	18	75	50	11	15	22	52	56	11	15	22	52
Layer 4															
1-A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	47	11	17	20	52	44	9	14	24	53
C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2-A	--	--	--	--	--	21	8	13	22	57	57	11	16	22	51
B	--	--	--	--	--	57	12	18	20	50	43	12	14	23	51
C	--	--	--	--	--	52	12	18	20	50	58	12	15	22	51
3-A	--	--	--	--	--	38	14	15	20	51	50	12	13	24	51
B	--	--	--	--	--	63	12	16	21	51	68	12	14	23	51
C	--	--	--	--	--	51	13	15	23	49	45	11	14	23	52
4-A	--	--	--	--	--	50	13	13	23	51	63	10	14	22	54
B	--	--	--	--	--	150	3	8	19	70	52	9	14	22	55
C	--	--	--	--	--	37	5	11	24	60	57	10	13	21	56

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