DETERMINATION OF SHELL CONTENT BY ACTIVATION ANALYSIS

Final Report

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Research Report No. FHWA-LA-78-123

Research Project No. 72-2S

Conducted By
LOUISIANA DEPARTMENT OF TRANSPORTATION
AND DEVELOPMENT, OFFICE OF HIGHWAYS
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

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AUGUST 1978

ACKNOWLEDGEMENT

The author wishes to thank the Californium Demonstration Center operated for the U. S. Department of Energy by Louisiana State University for the loan of californium-252 neutron sources that were used in this work. Also, Drs. Frank Iddings and John Courtney of the Louisiana State University Nuclear Science Center for their assistance during the course of this work.

IMPLEMENTATION

The study provides the Department with another tool in the quality control of materials used in highway construction. The findings of this study present a non-destructive method for determining the proportions of sand and shell in sand-shell mixtures used in roadway base construction. The study also results in another use for the technique developed under a previous research study (70-1ST).

The other methods that can be used to determine shell content in sand-shell mixtures are the chemical and hand methods. The chemical method involves the determination of weight loss as a percent, after subjecting a sample to the dissolving action of an acid solution. The small size of the sample used, five grams or less, and time required to completely dissolve the shell portion are the main drawbacks of this method. In the hand method, the shell particles of the sample are physically separate from the sand and percent content determined by weight of total material. This hand picking of the shell is very tedious as well as inaccurate.

The nuclear activation technique, used in this study, offers a rapid method in the determination of shell content of a sand-shell mixture. The sample size is also much larger, therefore more representative, than that used in either of the two methods discussed above. For implementation, it is recommended that this method of determining shell content be developed as a laboratory procedure, conducted on oven-dried material, and a separate calibration curve developed for each source of sand used on each respective project.

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INTRODUCTION

For many years shell has been used as an aggregate, alone or in combination with other materials, in base construction in southern Louisiana. This shell consists of clam (Figure 1) or reef (Figure 2) dredged from the bays and lakes along the coast. When used in highway base construction, it is generally combined with sand in volumetric proportions of 35% sand to 65% shell. At present, sand-shell proportioning is accomplished primarily by invoice quantities of individual components, trucked to the road site and then blade mixed on the roadway.

It is important that the proper proportion of sand-shell mixture be achieved, otherwise the support characteristics of the total pavement structure will be affected. Laboratory results (1)* have shown that a decrease in shell content below 65% will result in a lower strength class, thus a lower pavement structural coefficient. With other design criteria remaining constant, this would require additional base thickness than is generally used in Louisiana for sand-shell mixtures.

Initially, the objective was to determine if a gradation test could be developed whereby the Department could ascertain the proportion of shell in a natural or artificial mixture of sand and shell. However, early in the study it became apparent that this approach in determining the shell content would be very difficult and had little chance of success. The gradation tests of sand-shell mixture indicated that the soundness or quality of the shell can cause gradation differences for the same proportions of sand and shell. Reef shell used in Louisiana, for example, ranges from highly weathered (rotted reef) to relatively fresh and sound. The range of Los Angeles abrasion values for whole shell is generally 40 to 50% loss (2), with reef shell crushed and sized to not less than one inch (25.4 mm) having an abrasion loss of approximately 60%. Abrasion loss for shell fragments

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*Underlined numbers in parentheses refer to list of references.

Typical Clam Shell

FIGURE 1

Typical Reef Shell

FIGURE 2

that will pass a 3/8-inch sieve (9.525 mm) is approximately 30%.

As a result of this friable nature, degradation of shell normally occurs if the sand-shell is blade mixed (by motor patrol) on the roadway. Further degradation takes place during the compaction of the base material. In order to get a very tight-knitted end product, it is normal procedure in construction of sand-shell bases to produce shell fines by crushing the shell during compaction. These and other factors make it highly unlikely that gradation limits could be established in the laboratory to determine the proportion of shell.

For these reasons a change in scope was requested to use a non-destructive nuclear technique to determine the shell content. This technique, developed by Dr. Frank Iddings under previous research (3), involves the use of neutron activation analysis to determine calcium content of various highway construction materials. Since shell is composed principally of calcium in the form of calcium carbonate (92 to 96%), this approach showed more promise toward achieving the objective of this study. Sands normally used in sand-shell mixtures are predominately siliceous and contain approximately 1 to 2% calcium.

Basically, this technique consists of analyzing samples of sand-shell mixtures by producing a radioactive isotope of calcium (Ca-49), through neutron bombardment of the non-radioactive calcium (Ca-48). This is followed by measurement of the amount of Ca-49 by the technique of gamma spectroscopy. Gamma spectroscopy allows an unambiguous identification of the Ca-49 content which can be directly related to shell content. The neutron source for this work is the synthetic radioactive isotope californium-252 (Cf-252). For a more detailed discussion of this technique see reference (3).

SCOPE

The objective of this study is to determine if the neutron activation analysis technique, developed under Research Project 70-1ST, can be used to determine the shell content of a sand-shell base mixture.

In order to accomplish this objective, samples of sand and shell were obtained from different sources. The material sampled was artifically blended in the laboratory in various proportions, ranging from 90% sand - 10% shell to 15% sand - 85% shell, and then subjected to activation analysis. Each individual component (sand or shell) was mixed in various proportions with each other component from all sources in order to determine the variability produced by different combinations of materials. Tests results were evaluated for the linear relationship existing between varying proportions of each sand-shell combination.

METHODOLOGY

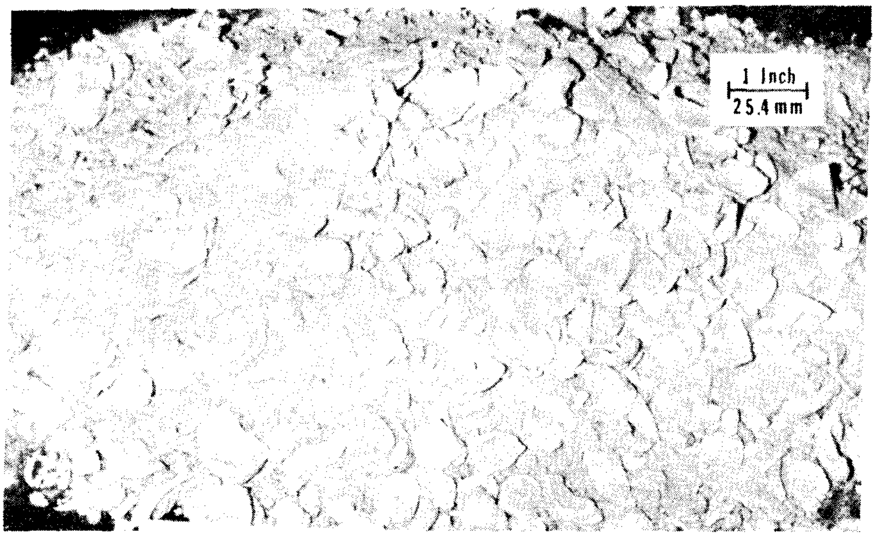
Activation Technique and Equipment

The method described here is based on the determination of the total shell content of a sample through measurement of the elemental calcium content of the sample. This is accomplished by subjecting samples of sand-shell mixtures of various proportions (Figures 3 and 4) to neutron bombardment, for a unit time, in a spherical activation/shield assembly (irradiator). A cross-sectional view and assembly with sample in "mouth" is shown in Figures 5 and 6. This neutron bombardment of the samples produces the radioisotope Ca-49, which decays, emitting characteristic gamma rays.

Neutron activation of the sand-shell mixtures produces a spectrum of gamma rays of various energy levels for the radioactive isotopes produced. Using gamma spectroscopy the specific energy of emission can be counted and analyzed. This analysis is done electronically by measuring emissions versus their energies. The equipment used in this study consists of a large detector (NaI(Tl)crystal) with photomultiplier tube and a small scaler or counting unit (Eberline Instrument Corp. Model MS-1). The detection and counting system is shown in Figures 7 and 8.

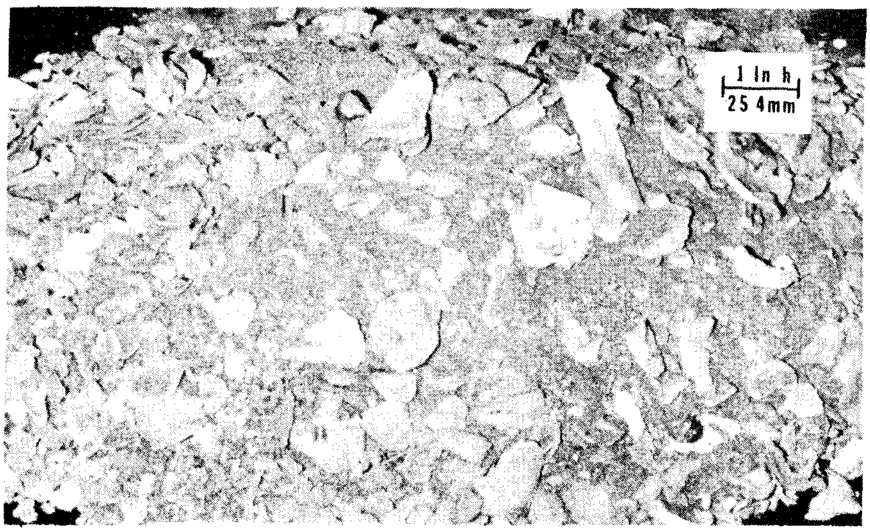
The data acquired, as indicated above, is then compared to the emissions of Ca-49 gammas from samples containing known amounts of shell or, as described in this study, to calibration curves developed through this technique.

The size of the Cf-252 source used in this work was approximately 140 micrograms.



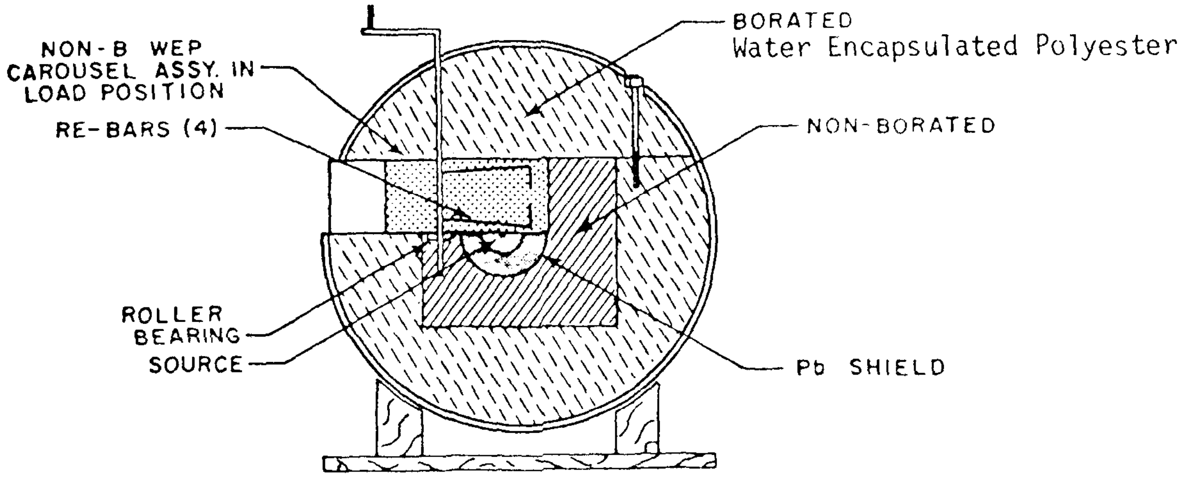
Ottawa Sand-Clam Shell Mixture

FIGURE 3



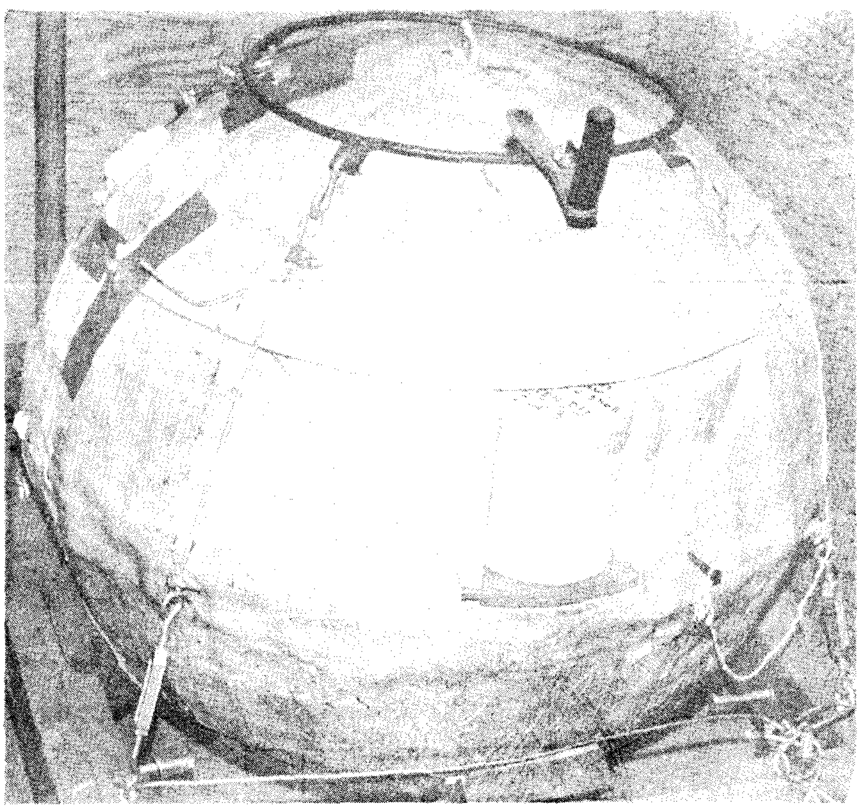
Ottawa Sand-Reef Shell Mixture

FIGURE 4



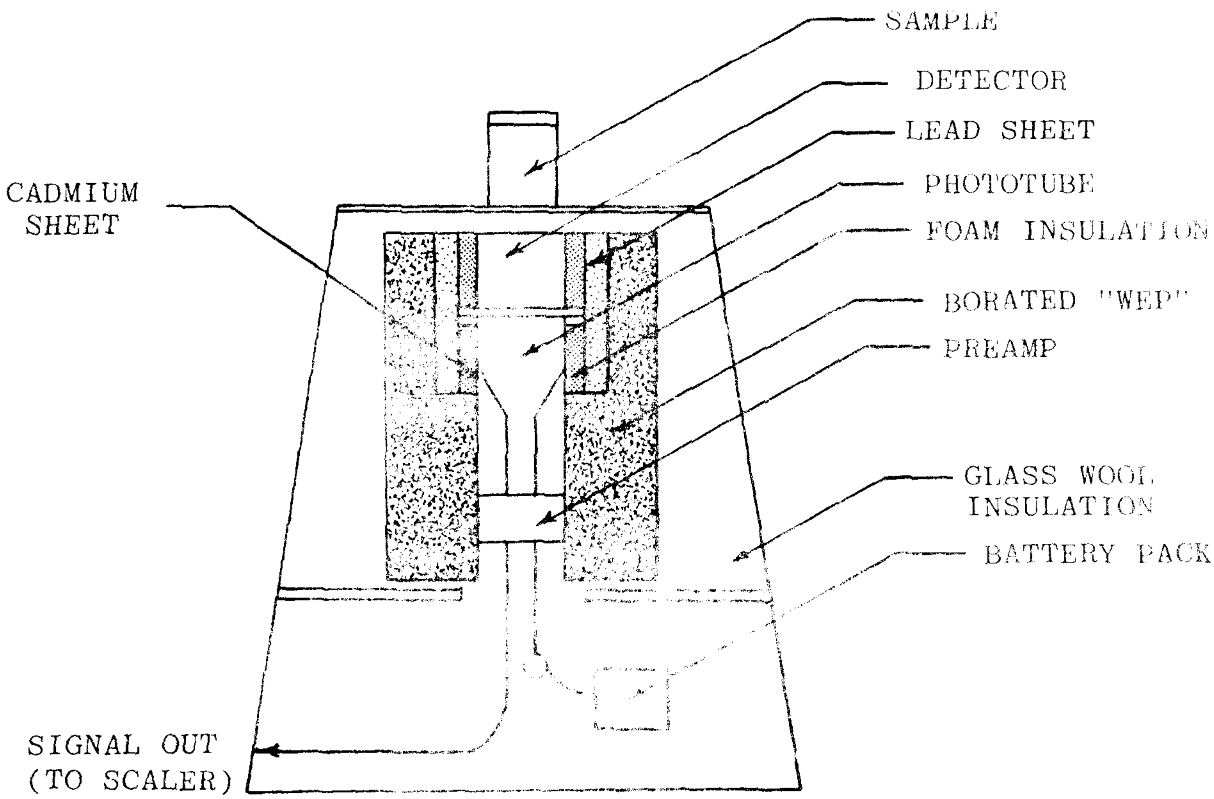
Cross Sectional View of Spherical Activation/Shield Assembly (Irradiator)

FIGURE 5



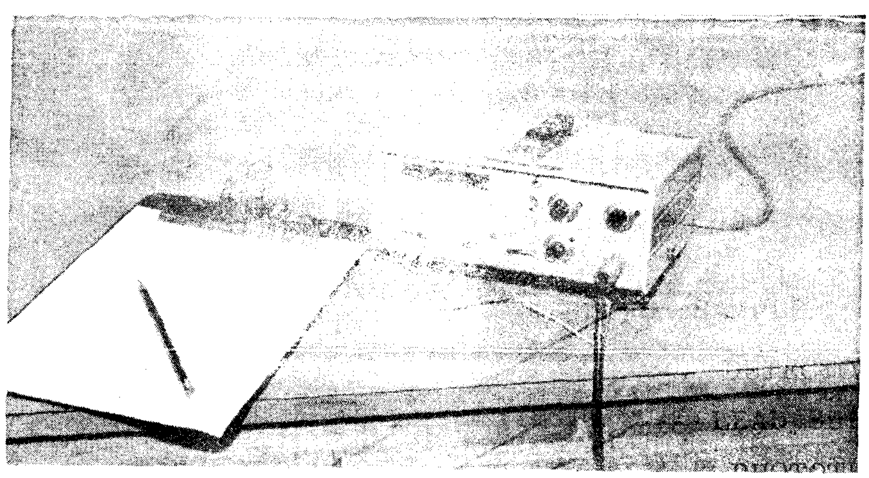
View of Spherical Activation/Shield Assembly with Sample in Mouth

FIGURE 6



Cross Sectional View of the Detector System Assembly

FIGURE 8



Eberline MS-1 Scaler

FIGURE 9

Materials Source

As indicated above, this method is based on measurement of the elemental calcium content of the sample. Virtually all the Ca-49 produced will be from the calcium of the shells contained in the sand-shell mixtures tested. Since the shell used in highway construction in Louisiana contains on the average 92% calcium carbonate, one sample each of reef and clam typical of that used was obtained from construction project stockpiles for testing. The source area of the reef was Atchafalaya Bay, southwest of Morgan City, and that of the clam was Lake Pontchartrain, immediately north of New Orleans.

Sands used to make the sand-shell samples tested were obtained from source areas which normally provide this type material for base construction in southern Louisiana. One sand was obtained from roadway stockpiles on a project near Raceland, with the source area being the Mississippi River north of New Orleans. Another, whose source area was the Calcasieu River was taken from a stockpile at Lake Charles. The third sand used in this study was the standard Ottawa sand commercially available. This sand is not used in construction of sand-shell bases, but was used here as a control since it is a very clean siliceous material.

Mineralogical and physical data for the sand and shell are listed in Table 3 of the appendix.

Sample Preparation

All samples of sand-shell tested were prepared in the laboratory, thus the shell and sand content were known in each case.

The sand and shell materials were dried in laboratory ovens at $230^{o}F\pm$ ($110^{o}C\pm$). The shell was crushed, to a minumim of 95% passing the No. 3/4 sieve (19.05 mm), in a jaw crusher in order to simulate, to some degree, the crushed shell existing in-place after the base course is completed.

Each sand was then mixed with each other shell type, at predetermined volumetric proportions, resulting in six different combinations of materials for testing. A set of samples, for each combination of materials, consisted of sand and shell combined in various proportions generally ranging from 90% sand - 10% shell to 15% sand - 85% shell. Three samples were prepared for testing at each proportion within a set (see Table 1). For actual fabrication of samples, each volumetric proportion was converted to its' respective proportion by weight. It should be noted here that normally all proportioning in the field is volumetric, specifically by truckbed measurement. The total dry weight of each sample tested was 5.73 pounds (2.6 kilograms).

Oven dried samples were tested at two different time sequences; ten minute activation-two minute decay-ten minute nuclear count (10-2-10) and five minute activation-one minute decay-five minute nuclear count (5-1-5). For the samples tested at 10-2-10, the two components, of each sample, were trowel mixed by hand, placed in plastic bags and inserted in cardboard cylinder containers, 5 inches in diameter by 6 inches in height. These samples were later retested at 5-1-5 testing sequence with the plastic bags removed.

In order to determine the effect of moisture, water was added, in increments of 4, 8, and 12% (by dry weight), to samples prepared and placed in plastic bags, as stated above, and tested at 10-2-10 sequence.

<u>Sample Testing</u>

Samples were placed in the irradiator for ten minutes, removed and after two minutes (allowing for transfer and some decay time), were placed on the detector, where counts were taken for ten minutes. Samples were irradiated from the bottom, that is, placed so that the Cf-252 source was centered underneath the base of the cylinder.

Once the first sample had been irradiated and while counts were being taken, a second sample was placed in the irradiator. Thus each successive sample, after the first, was ready to be placed on the detector shortly after the preceding sample had been removed. In the case of samples tested at 5-1-5, each sample requires eleven minutes to complete the entire process and allows eight samples to be tested in an hour.

Background radiation was determined before, periodically during and at the end of each day's testing. These values were used to correct the readings taken on samples for this naturally occurring radiation.

DISCUSSION OF RESULTS

Statistical Analysis

It has been shown elsewhere (3) that quantitative analysis of particular calcium-rich compounds can be accomplished by the neutron activation technique. This was done for soil-cement and concrete mixtures in which the Portland Cement content of the two materials is determined by plotting nuclear counts of an activated "unknown" onto a calibration curve developed from known proportions of the material being tested. The data points used to establish the calibration curves for the above materials showed a linear relationship (counts vs. percent cement), with the average standard error in cement determination being ± 5% of the cement added (68% of the time).

In order to determine if a same linear relationship existed for count vs. percent shell, the activation results of each set of samples were subjected to regression correlation analysis. The statistical data in Figures 11 through 40 do indicate a strong linear relationship for nuclear count vs. percent shell. Twenty-four of the 30 sets tested had coefficient of determination (R^2) values between 0.9043 and 0.9942. Of the remaining six sets, five had R^2 values of between 0.8637 and 0.8721 and the sixth was 0.7614.

The R^2 values established for the sets of sand-shell samples tested do not alone completely define the precision of this method in determining shell content. In order to have confidence in this procedure, the results obtained must be expected to fall within some acceptable limits of the corresponding absolute values; in this case the calibration curve. The negative limit, since this is the critical level here, must be such that the respective triaxial class of the sand-shell mixture will be 2.2 or greater; thereby resulting in a pavement coefficient which conforms to that used in Louisiana for this type base course material (4).

TABLE 1

SCHEDULE OF SAMPLES TESTED

OVEN DRY SAND-SHELL MIXTURES

Testing Time*	10-2-10						5-1-5					
Materials	Raceland Sand		L. Charles Sand**		Ottawa Sand		Raceland Sand		L. Charles Sand		Ottawa Sand	
	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam
Sets	1	1	1	1	1	1	1	1	1	1	1	1
Proportions	8	8	8	8	8	8	8	6	8	8	8	8
No. of Samples	24	24	24	24	24	24	24	18	24	24	24	24

WET SAND-SHELL MIXTURES

Testing Time	10-2-10																	
Moisture Added-%	4						8						12					
Materials	Raceland Sand		L. Charles Sand		Ottawa Sand		Raceland Sand		L. Charles Sand		Ottawa Sand		Raceland Sand		L. Charles Sand		Ottawa Sand	
	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam	Reef	Clam
Sets	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Proportions	4	4	4	4	4	4	7	4	4	4	4	4	4	4	4	4	4	4
No. of Samples	12	12	12	12	12	12	21	12	12	12	12	12	12	12	12	12	12	12

* Activation-Decay-Nuclear Reading in minutes

** Lake Charles Sand

Previous research (1) indicates triaxial values of sand-shell mixtures containing 55% shell by volume are 2.5 or greater and those containing 60% shell by volume are 2.0 or greater. Therefore, sand-shell mixtures containing a minimum of 58% shell can be expected to have a triaxial class of 2.2 or greater. Thus, since 65% shell is the present standard requirement in sand-shell base construction, a standard error of ±7% could be set for the test with the statistical probability than the resulting triaxial class values, within this limit, will be 2.2 or greater 95% of the time.

Statistical analysis of test results for the 30 sets of sand-shell mixtures indicate a maximum standard error for any single set, irrespective of the variables introduced, was ±7.0% of the calibration curve at the 95% confidence level (Figure 14). The mean standard error for the 30 sets tested was ±4.2%. The data for each respective set of samples tested are listed in Figures 11 through 40. Therefore, determination of shell content, of a sand-shell mixture, can be achieved by activation analysis within the statistical limits established above.

Effect of Testing Time Sequences

The oven-dry combinations of sand and shell were tested at two different time sequences. One set each of the six combinations of materials was tested, first at 10-2-10 and then at 5-1-5 time intervals.

The sample tested at 5-1-5 minutes did show a slight overall decrease in standard error with a range of ±2.0% to ±2.9% as compared to ±1.9% to ±3.5% for a testing time sequence of 10-2-10. Based on these results, a testing time of 5-1-5 minutes is recommended for future testing. These results are shown in Figures 11 through 16 (10-2-10) and 17 through 22 (5-1-5).

Effect of the Sands on Nuclear Counts

Samples of the sands, free of shell, were subjected to neutron irradiation and counts were taken. The results, shown on Table 2, indicated a large difference between the Raceland sand and the other two. The cause for this difference was not determined. A wet chemistry check of the calcium content indicated less than 1% for each of the three sands. The mineralogical analysis of the sands indicated a slight organic content in the Raceland sand which was the major difference between the three; however, this is not considered to be the cause. The difference in nuclear count affects the slope of the calibration curve, as shown in Figure 9, which prevents the use of one calibration curve for all sources of sands (Figure 10). No major problem results since a calibration curve generated for each source of material used in combination with shell will cancel out this effect.

The activation results of reef and clam shell used in this study are also shown in Table 2. The results did not indicate any great difference in nuclear count concerning the two shells.

Effect of Moisture in Sand-Shell Samples

Since water is a moderator of neutrons, samples containing various moisture contents were subjected to activation analysis for determination of its effect on the nuclear counts. Statistical results and calibration curves for each set are shown in Figures 23 through 40. The results of these tests did not indicate water in sand-shell samples would cause any additional variations in nuclear counts than that found for sand-shell sets tested dry. At high moisture contents (8 to 12%), it is conceivable that this water could drift, as a result of gravity, and collect at the bottom of the sample container when two or more days elapse between sampling and testing. This condition would increase the chance of introducing another variable in the testing. Even though no problem was indicated in this work due to moisture in the sample, theoretically it can cause problems, and for this reason it is recommended all testing be done on oven-dried sand-shell samples.

SUMMARY AND CONCLUSIONS

Neutron activation analysis technique does provide a viable method of determining shell content of a sand-shell mixture. There exists a strong linear relationship between nuclear count (gamma) and percent shell (reef and/or clam) after subjecting sand-shell mixtures to neutron irradiation. Test results for 30 sets of sand-shell mixtures indicate a maximum standard error for any single set to be $\pm$ 7.0% of the calibration curve at the 95% confidence level. The mean standard error for the 30 sets tested was $\pm$4.2%. Therefore, determination of shell content can be achieved by this technique within the statistical limit established.

Testing time sequence of five-minute activation-one-minute decay-five-minute count resulted in a slightly smaller range in statistical standard error values than testing time sequence of ten-minute activation-two-minute decay-ten-minute count. Therefore, the 5-1-5 testing time is recommended for this type of aggregate evaluation.

Sand from one source may result in widely different nuclear counts, after activation, than that of sands from other sources. This effect can be negated by generating a separate calibration curve for each source of sand used.

Varying the moisture content in sand-shell samples did not appear to cause any additional variations than those found for the oven-dried samples tested. However, it is recommended that all sand-shell samples tested by this technique be oven-dried prior to testing.

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3. Iddings, F. A. and Arman, Ara, Determination of Cement Content in Soil-Cement Mixtures and Concrete, Louisiana State University, Engineering Research Bulletin No. 114, April, 1977.

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APPENDIX

GLOSSARY OF STATISTICAL DATA

N = number of test samples

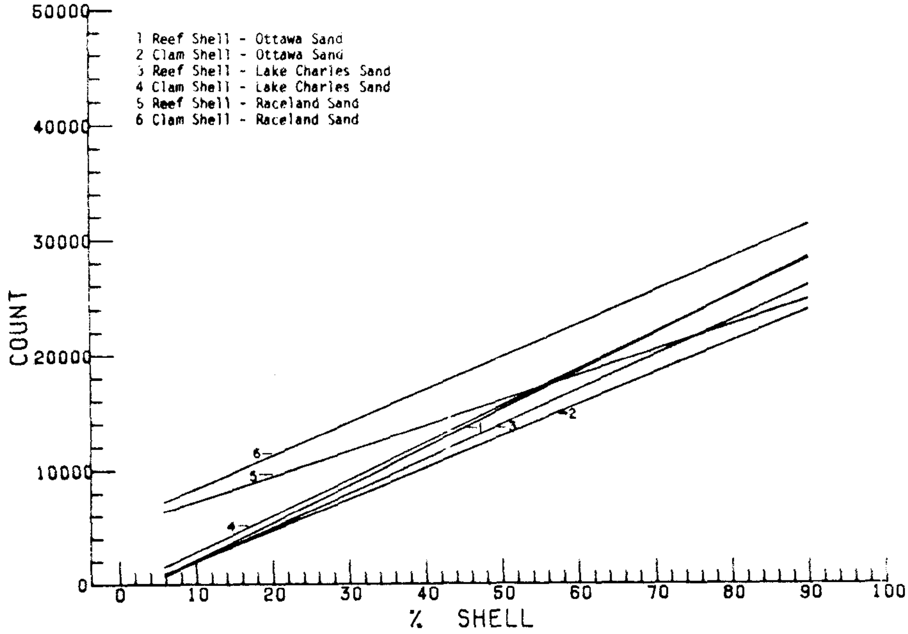
R^2 = coefficient of determination

b = slope of line (units shown x 10^2)

a = y intercept (units shown x 10^2)

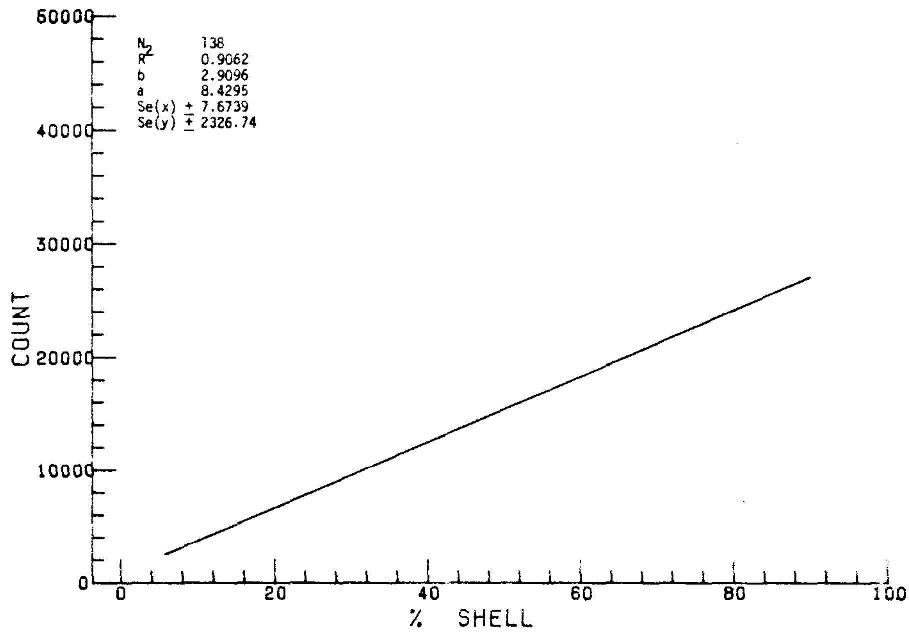
Se(x) = one standard error of shell content (x on y)

Se(y) = one standard error of counts (y on x)



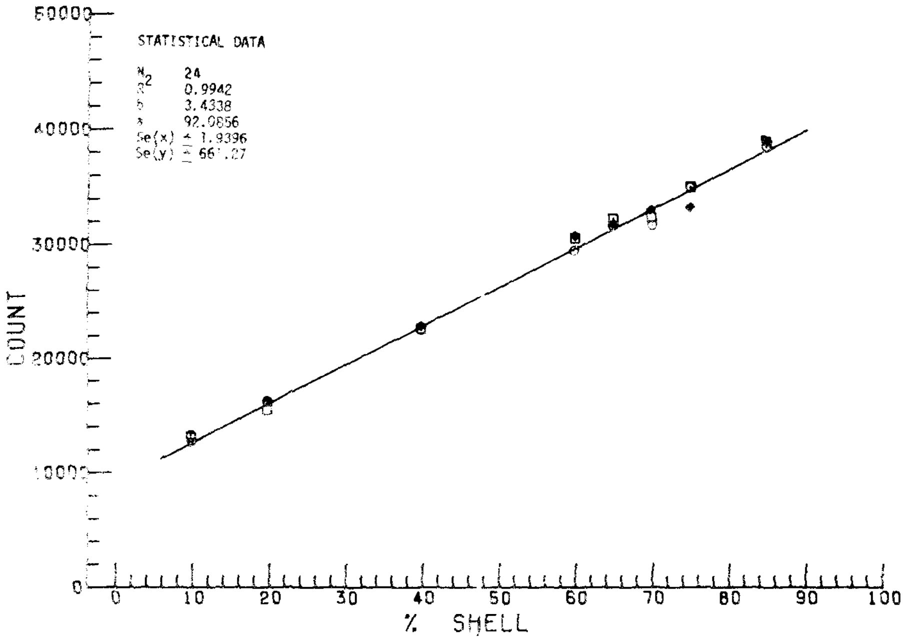
Calibration Curves for Sand-Shell Sets (5-1-5)

FIGURE 9



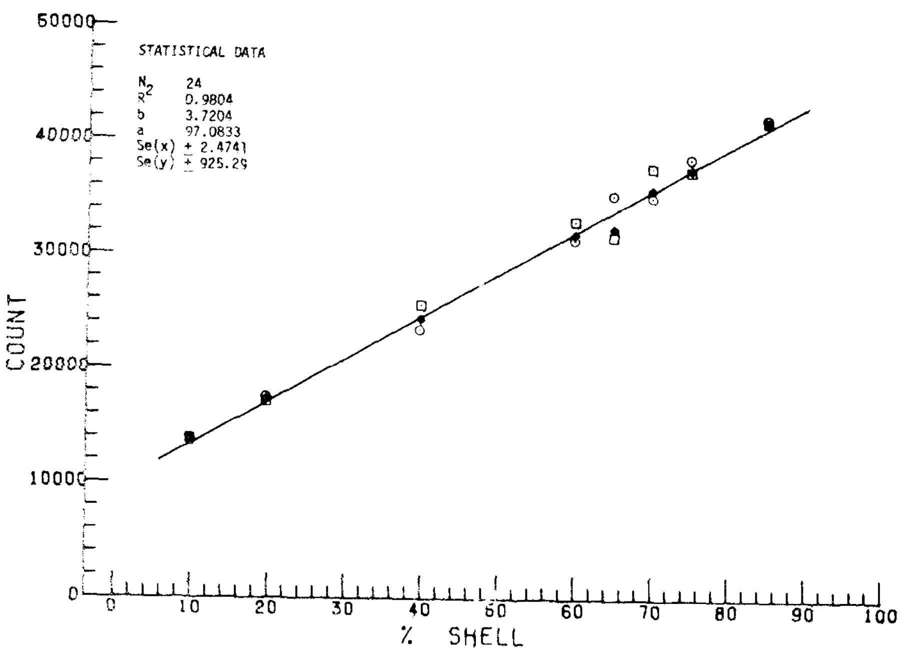
Composite Calibration Curve of Sand-Shell Sets (5-1-5)

FIGURE 10



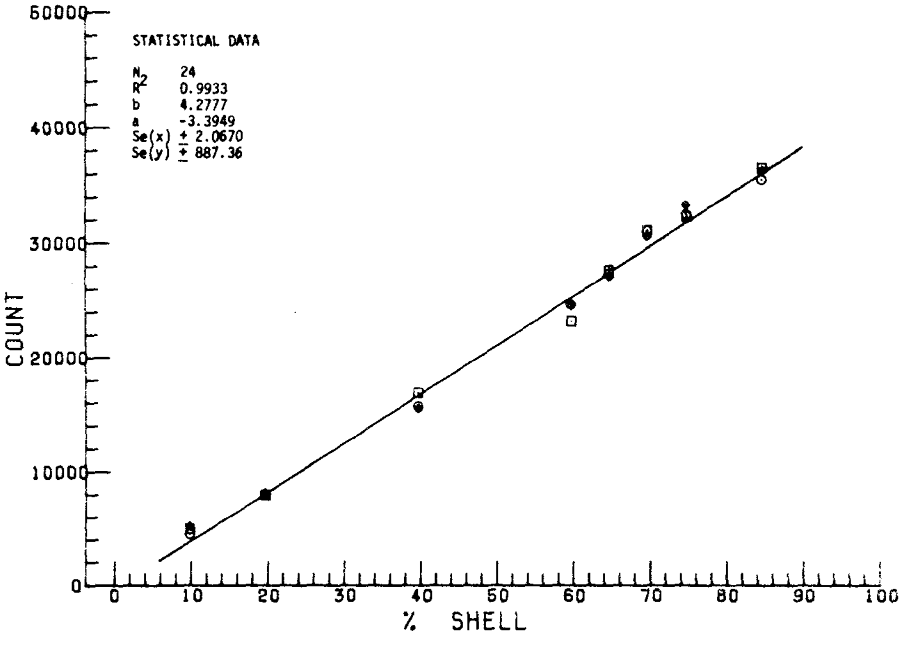
Raceland Sand-Reef Shell Calibration Curve (10-2-10)

FIGURE 11



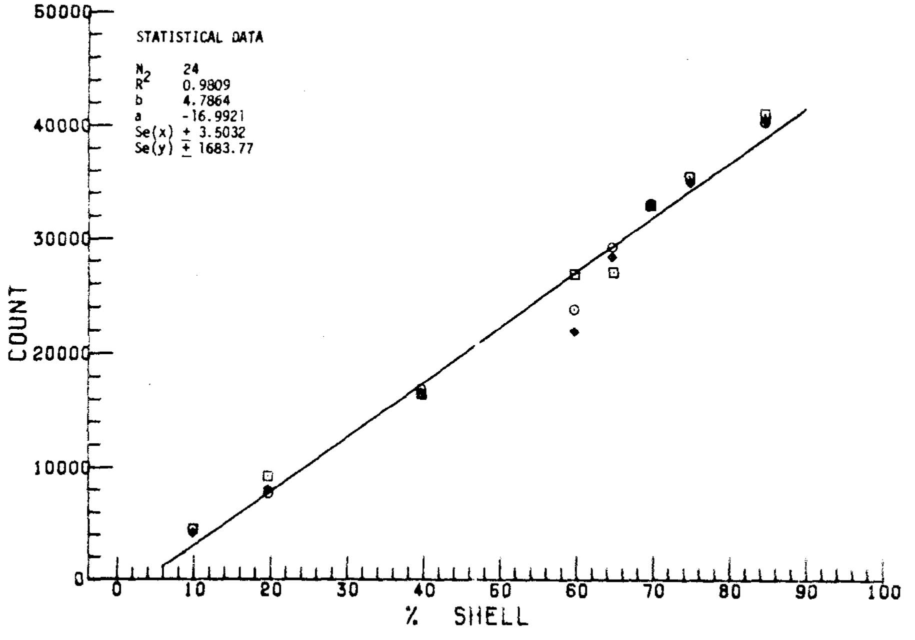
Raceland Sand-Clam Shell Calibration Curve (10-2-10)

FIGURE 12



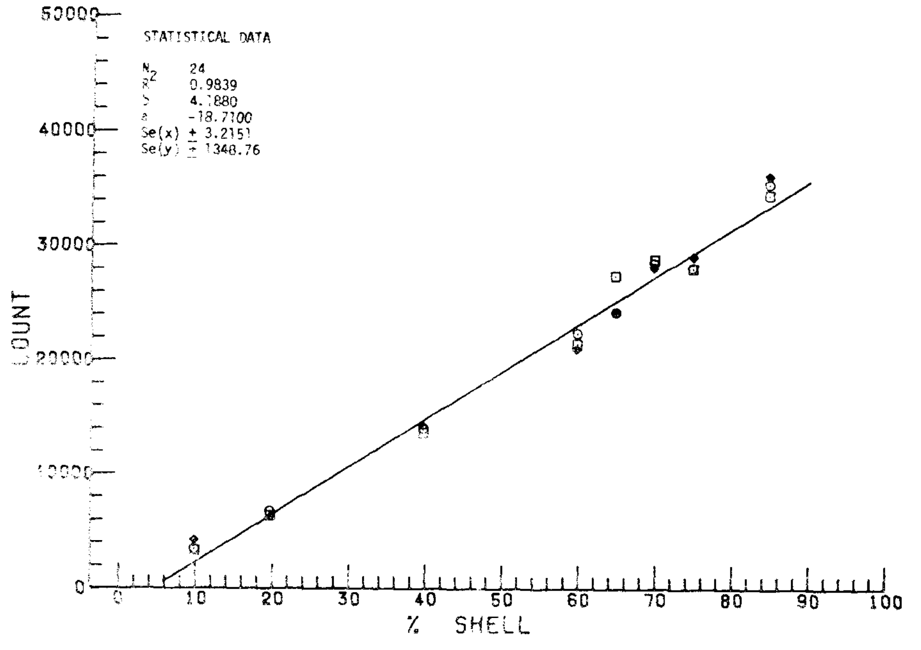
Lake Charles Sand-Reef Shell Calibration Curve (10-2-10)

FIGURE 13



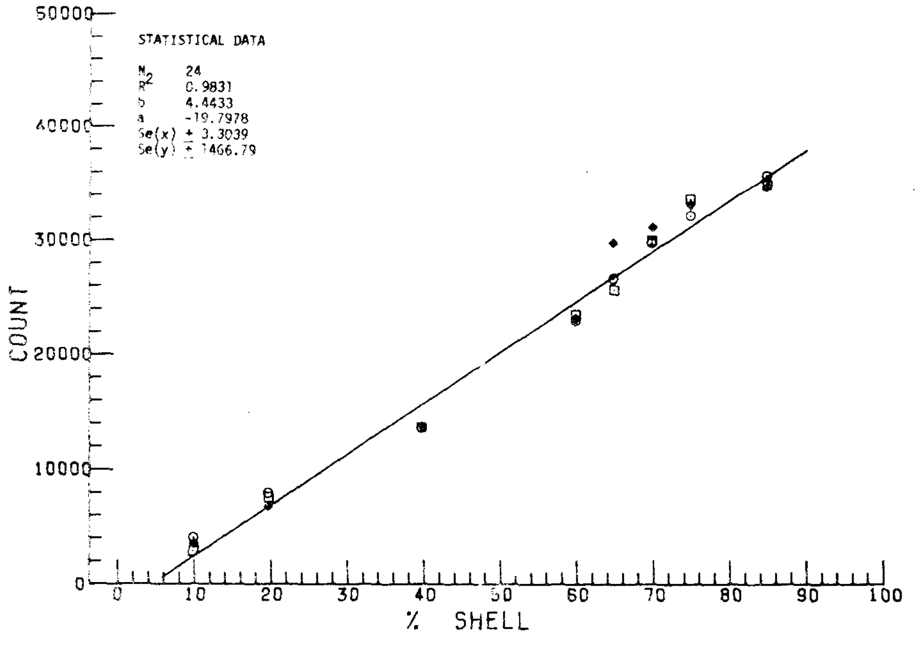
Lake Charles Sand-Clam Shell Calibration Curve (10-2-10)

FIGURE 14



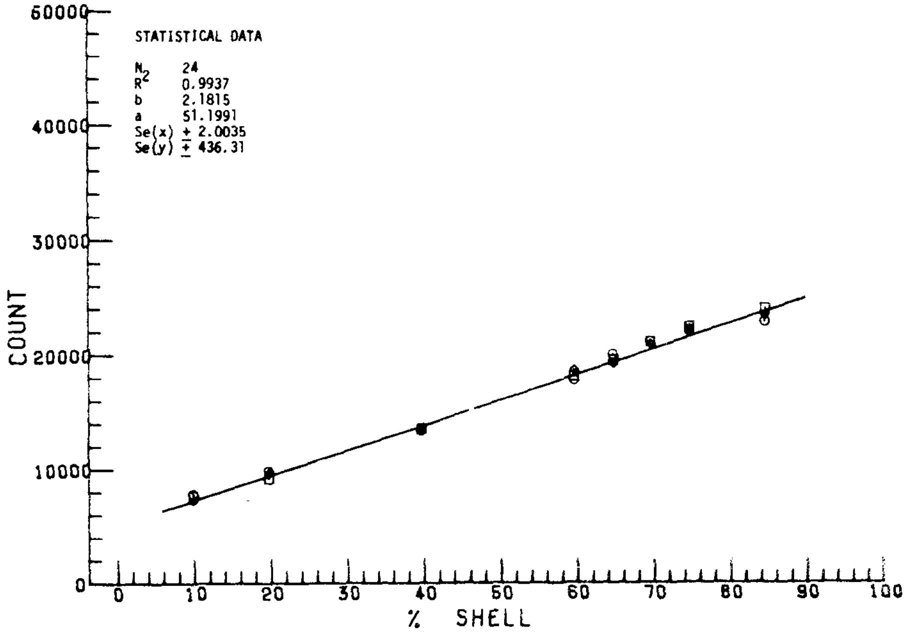
Ottawa Sand-Reef Shell Calibration Curve (10-2-10)

FIGURE 15



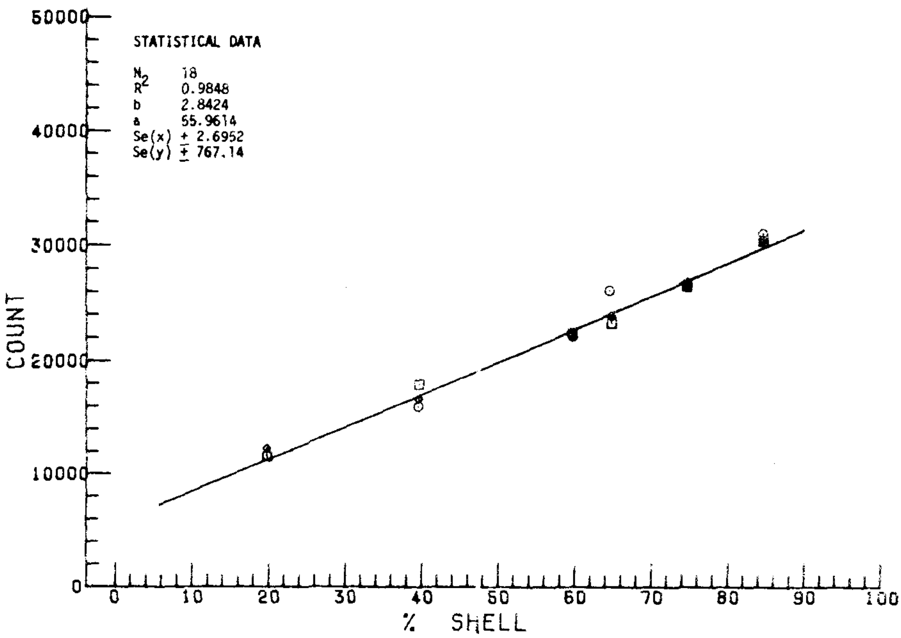
Ottawa Sand-Clam Shell Calibration Curve (10-2-10)

FIGURE 16



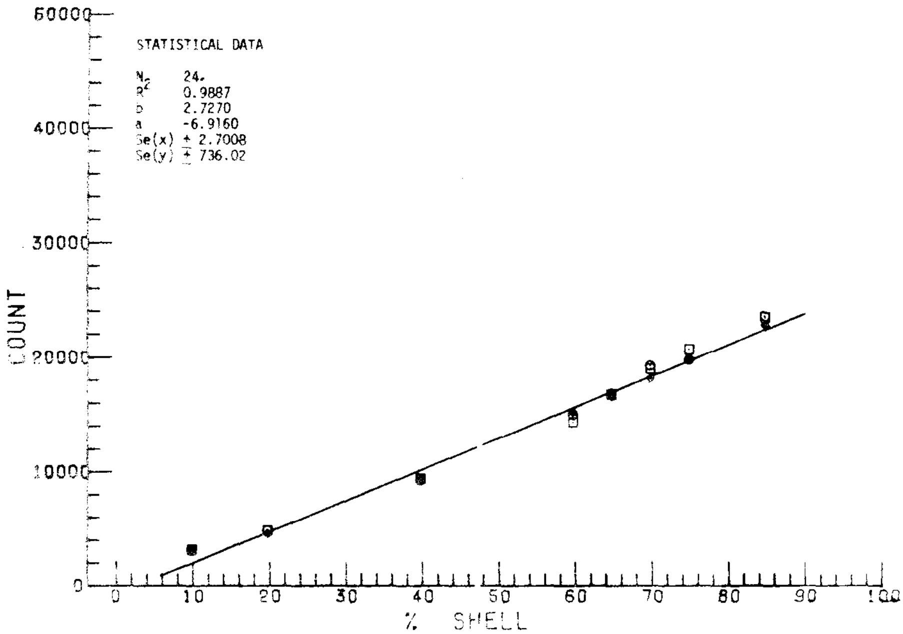
Raceland Sand-Reef Shell Calibration Curve (5-1-5)

FIGURE 17



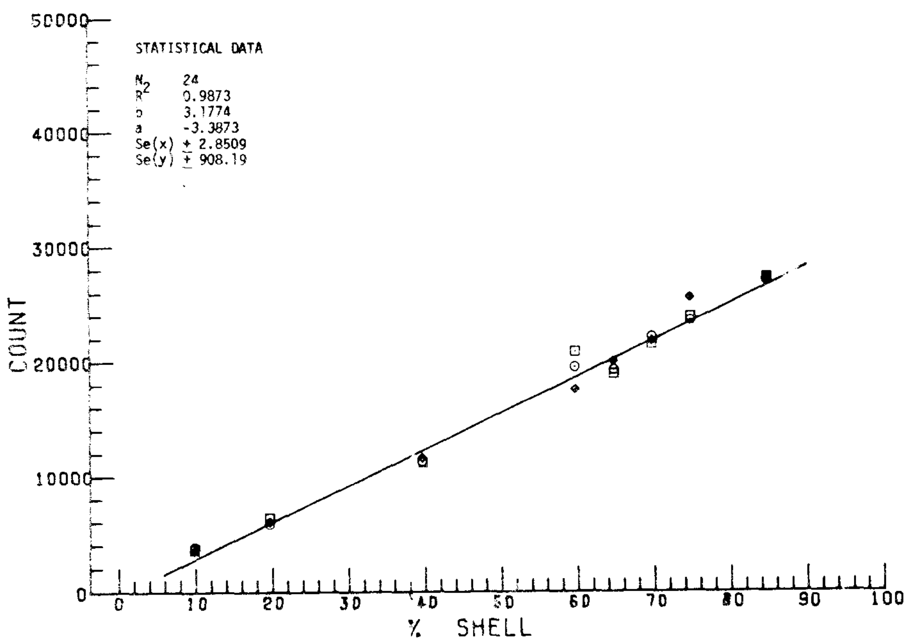
Raceland Sand-Clam Shell Calibration Curve (5-1-5)

FIGURE 18



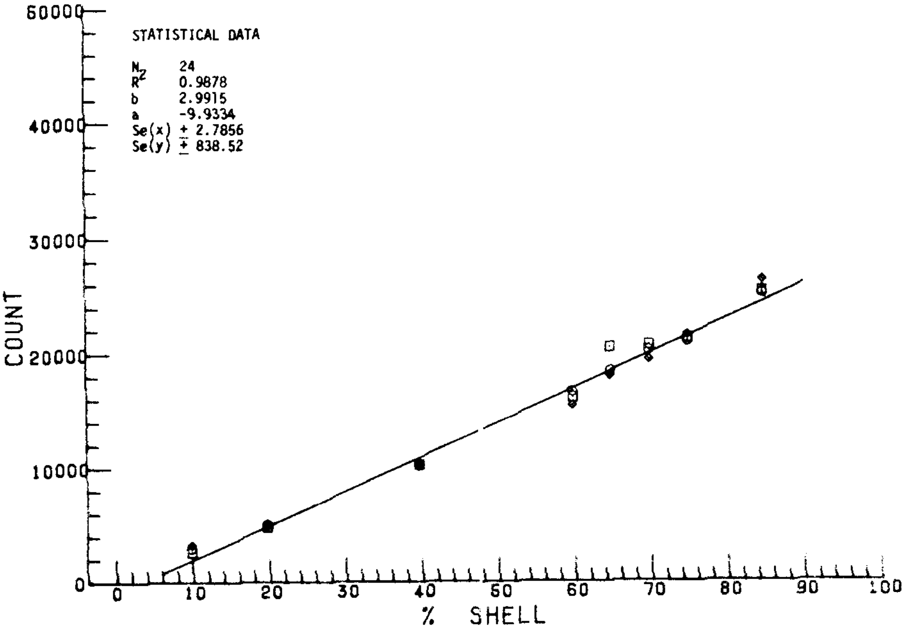
Lake Charles Sand-Reef Shell Calibration Curve (5-1-5)

FIGURE 19



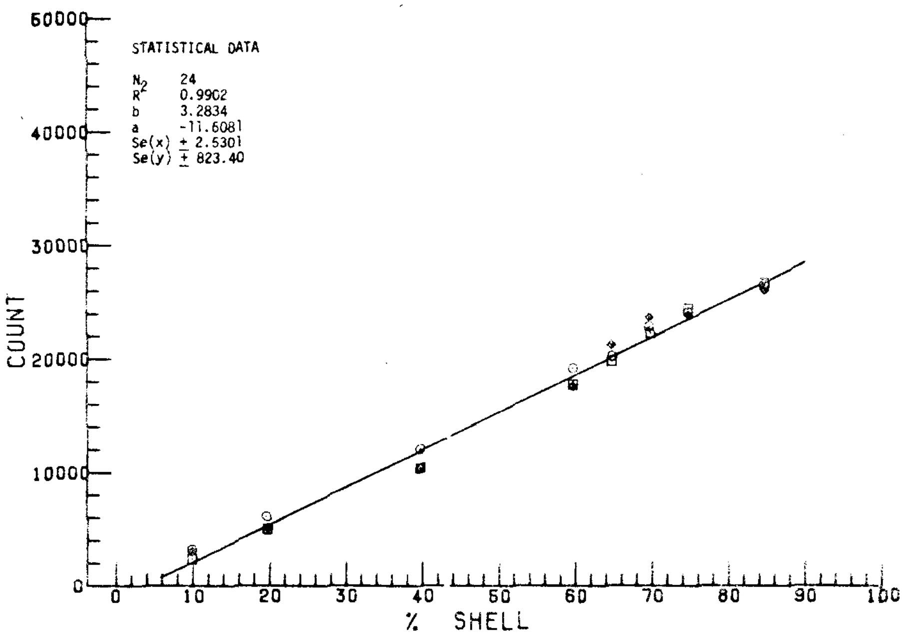
Lake Charles Sand-Clam Shell Calibration Curve (5-1-5)

FIGURE 20



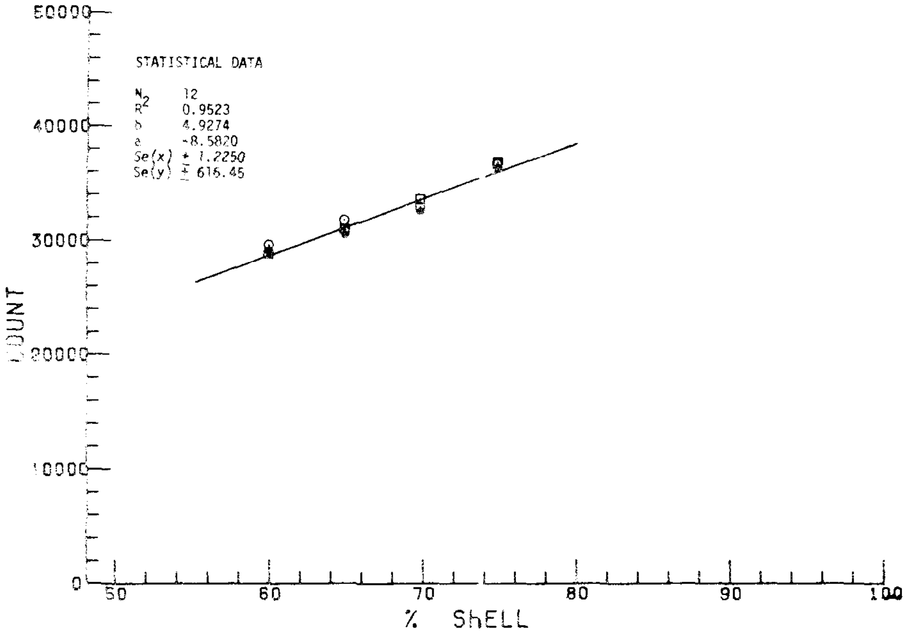
Ottawa Sand-Reef Shell Calibration Curve (5-1-5)

FIGURE 21



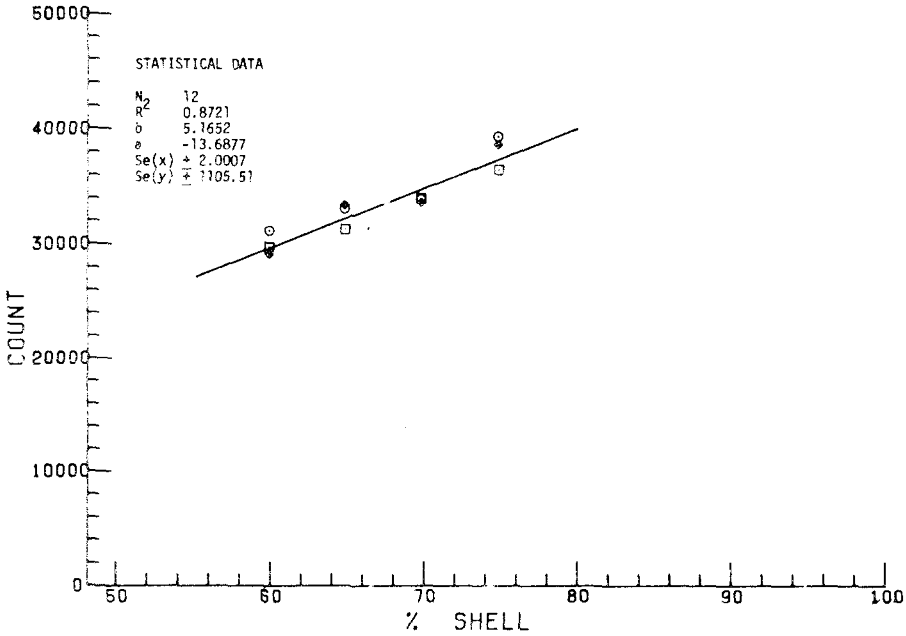
Ottawa Sand-Clam Shell Calibration Curve (5-1-5)

FIGURE 22



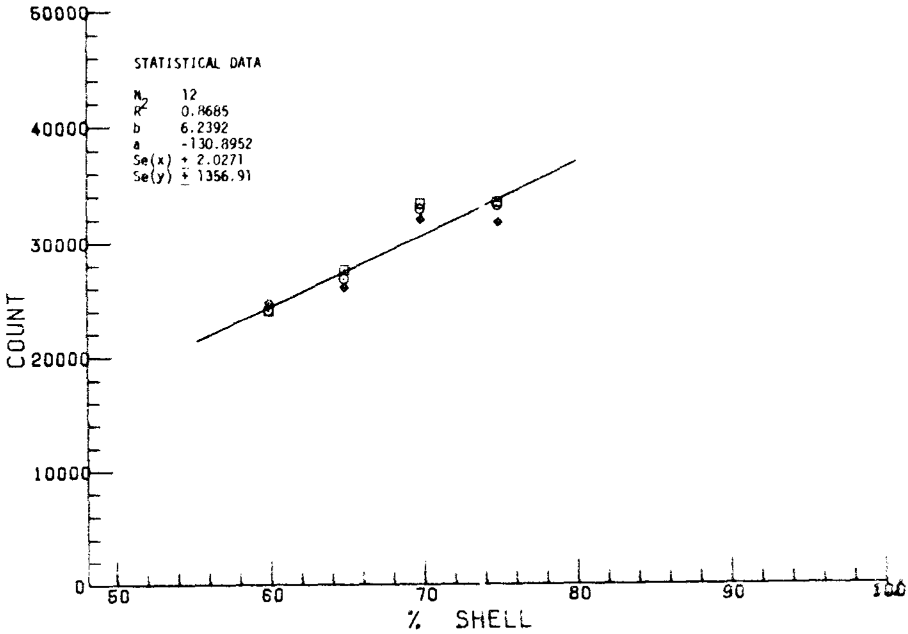
Raceland Sand-Reef Shell Calibration Curve
(10-2-10----4% Moisture Added)

FIGURE 23



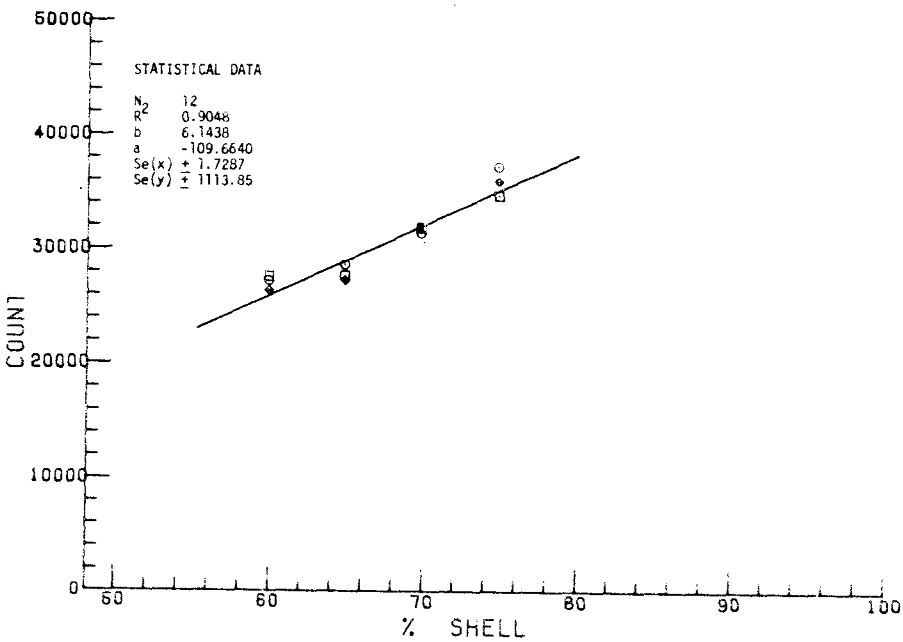
Raceland Sand-Clam Shell Calibration Curve
(10-2-10----4% Moisture Added)

FIGURE 24



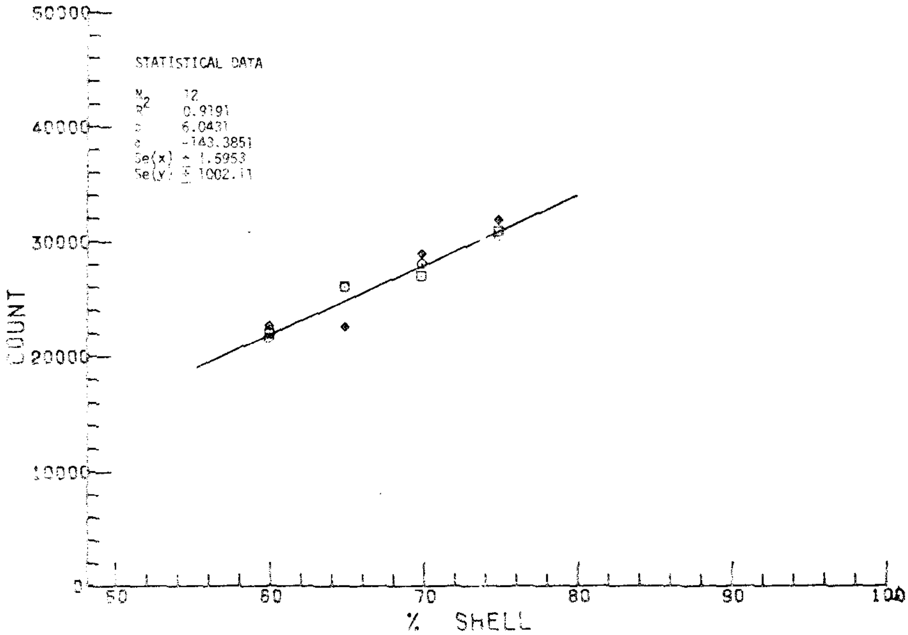
Lake Charles Sand-Reef Shell Calibration Curve
(10-2-10----4% Moisture Added)

FIGURE 25



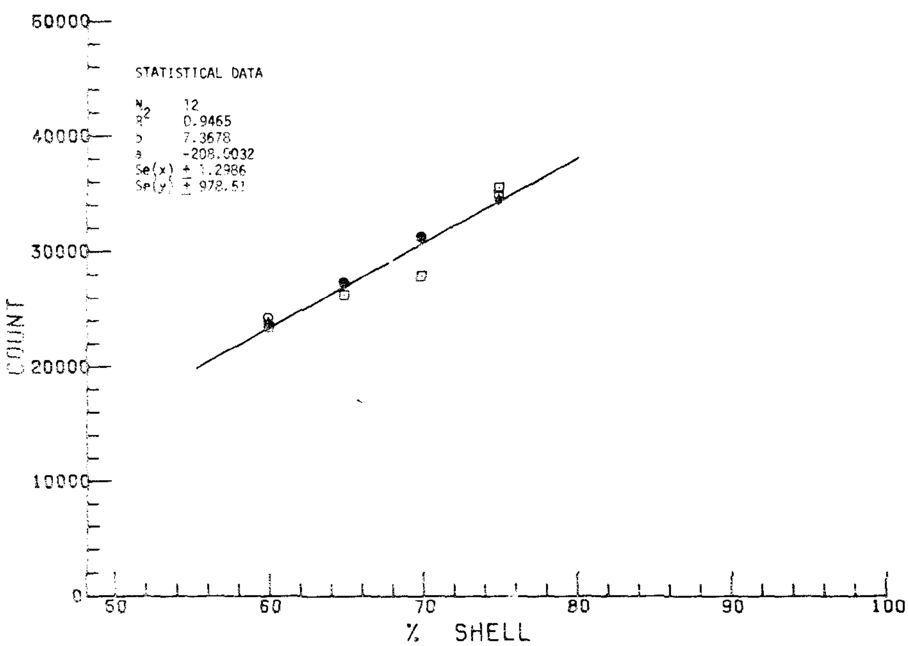
Lake Charles Sand-Clam Shell Calibration Curve
(10-2-10----4% Moisture Added)

FIGURE 26



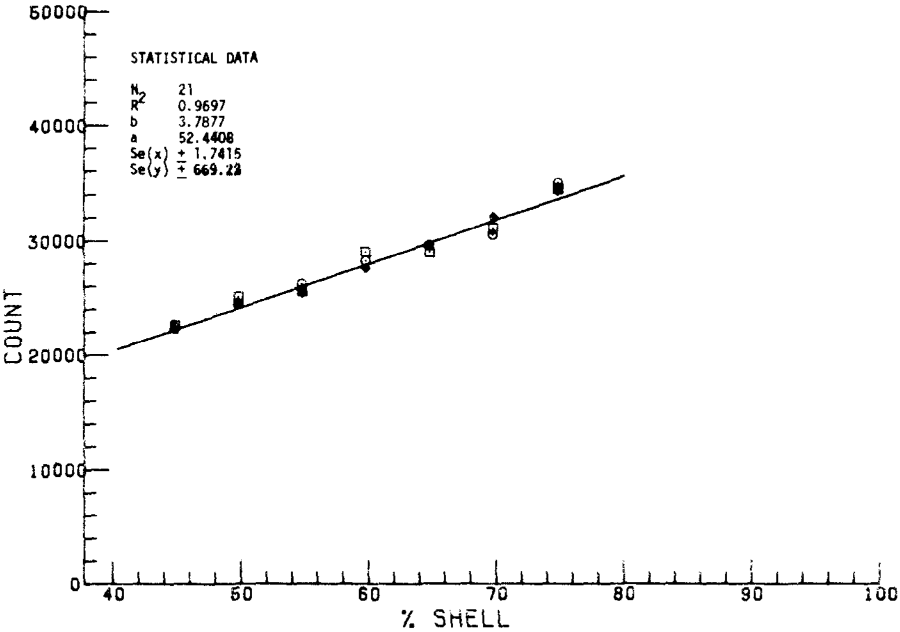
Ottawa Sand-Reef Shell Calibration Curve
(10-2-10----4% Moisture Added)

FIGURE 27



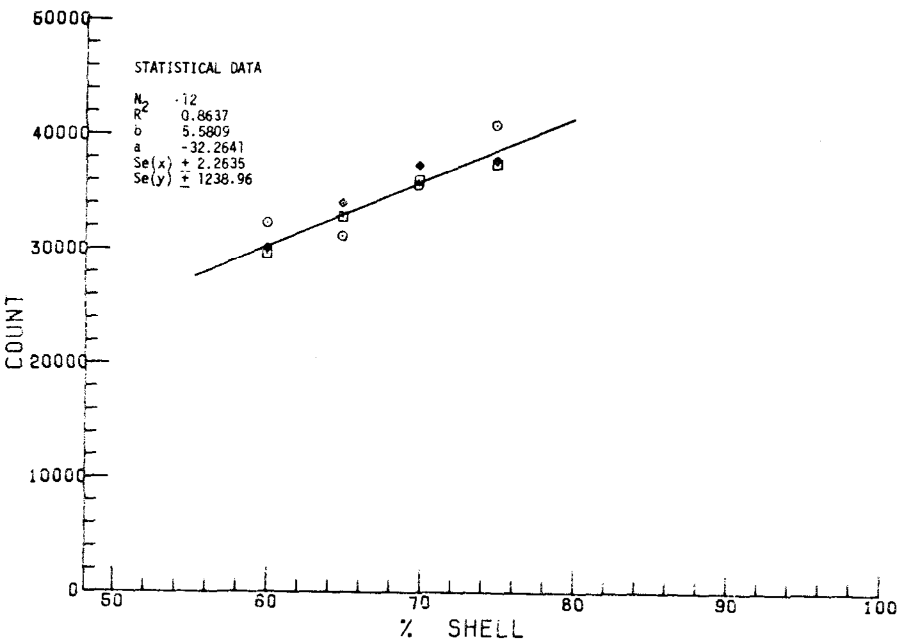
Ottawa Sand-Clam Shell Calibration Curve
(10-2-10----4% Moisture Added)

FIGURE 28



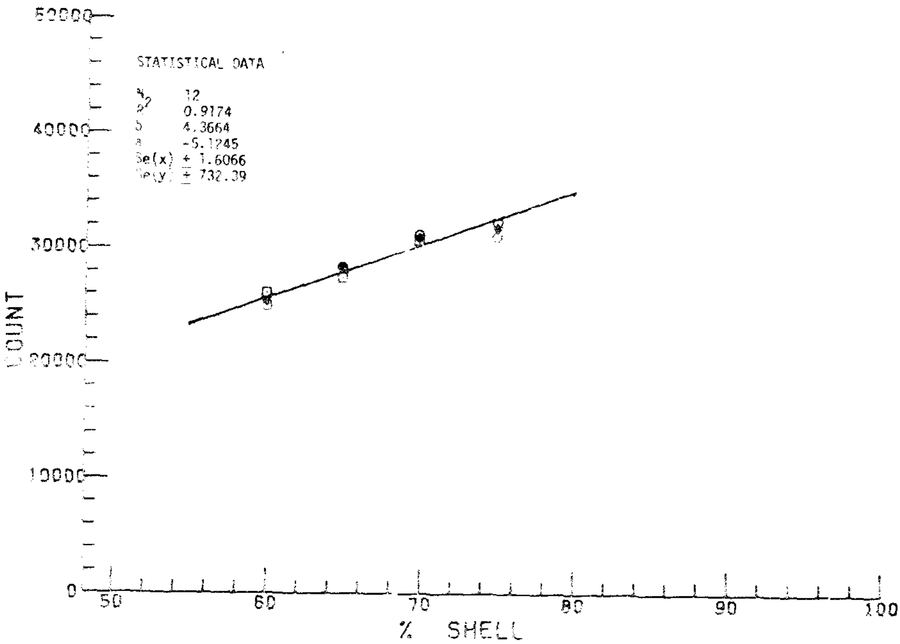
Raceland Sand-Reef Shell Calibration Curve
(10-2-10----8% Moisture Added)

FIGURE 29



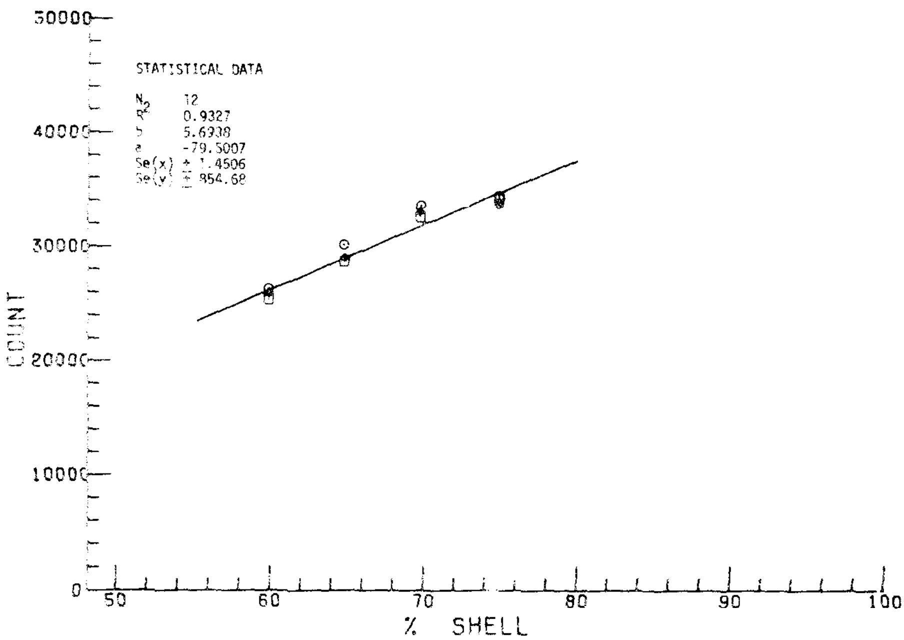
Raceland Sand-Clam Shell Calibration Curve
(10-2-10----8% Moisture Added)

FIGURE 30



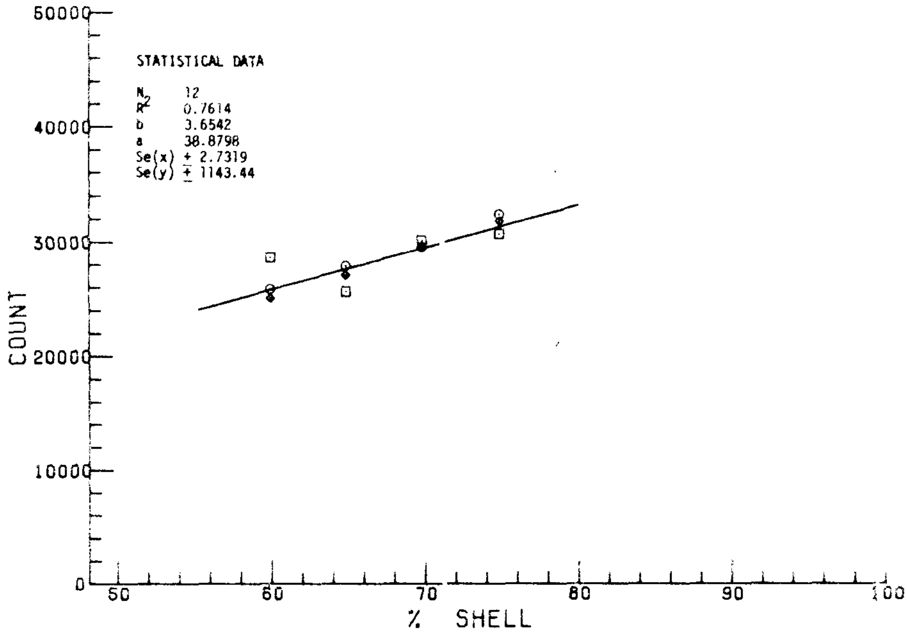
Lake Charles Sand-Reef Shell Calibration Curve
(10-2-10----8% Mositure Added

FIGURE 31



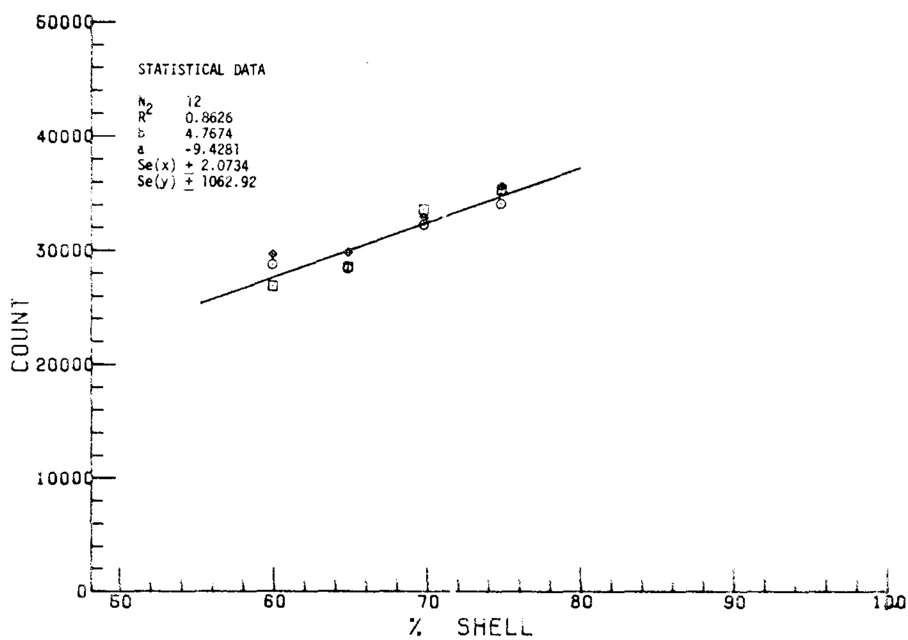
Lake Charles Sand-Clam Shell Calibration Curve
(10-2-10----8% Moisture Added)

FIGURE 32



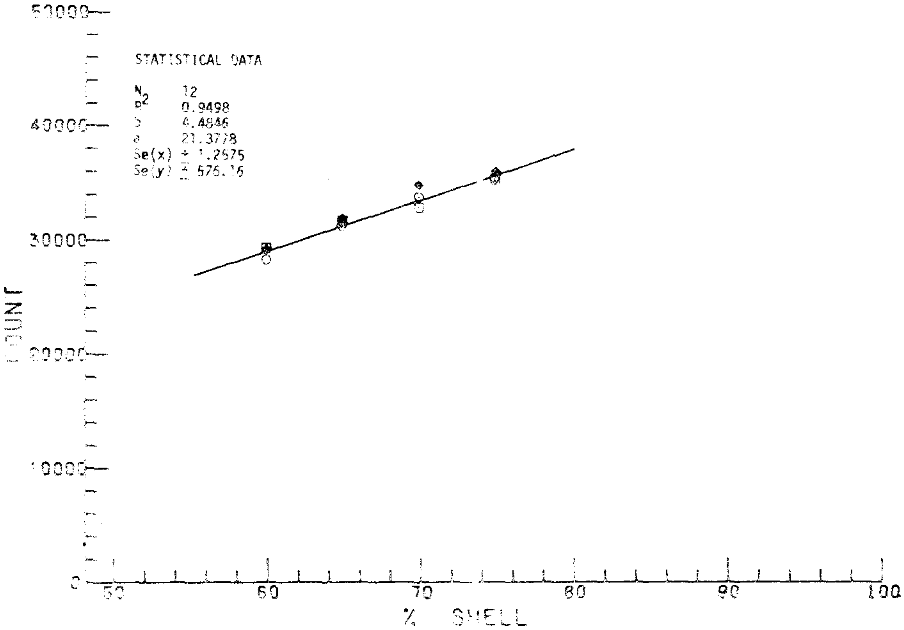
Ottawa Sand-Reef Shell Calibration Curve
(10-2-10----8% Moisture Added)

FIGURE 33



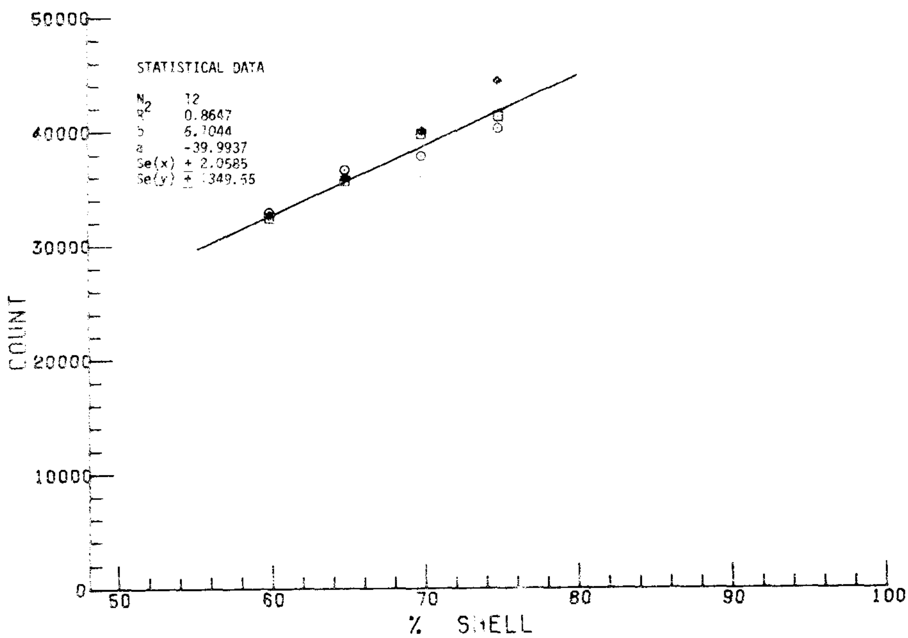
Ottawa Sand-Clam Shell Calibration Curve
(10-2-10----8% Moisture Added)

FIGURE 34



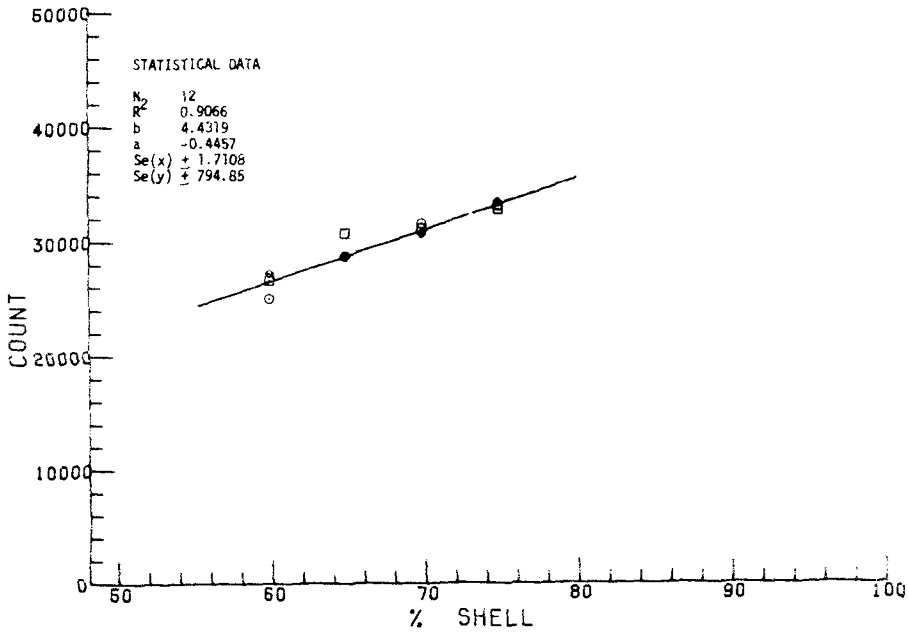
Raceland Sand-Reef Shell Calibration Curve
(10-2-10----12% Moisture Added)

FIGURE 35



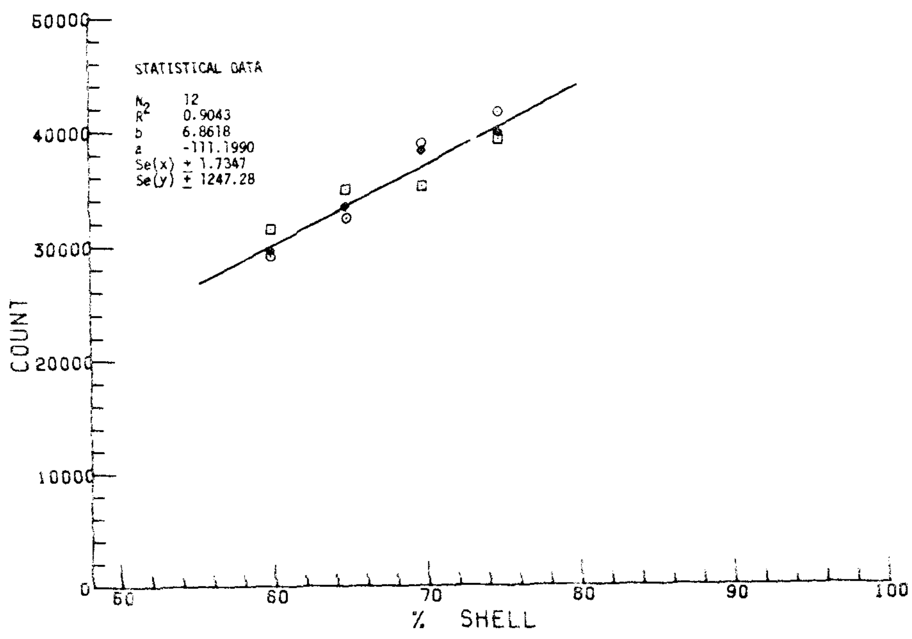
Raceland Sand-Clam Shell Calibration Curve
(10-2-10----12% Moisture Added)

FIGURE 36



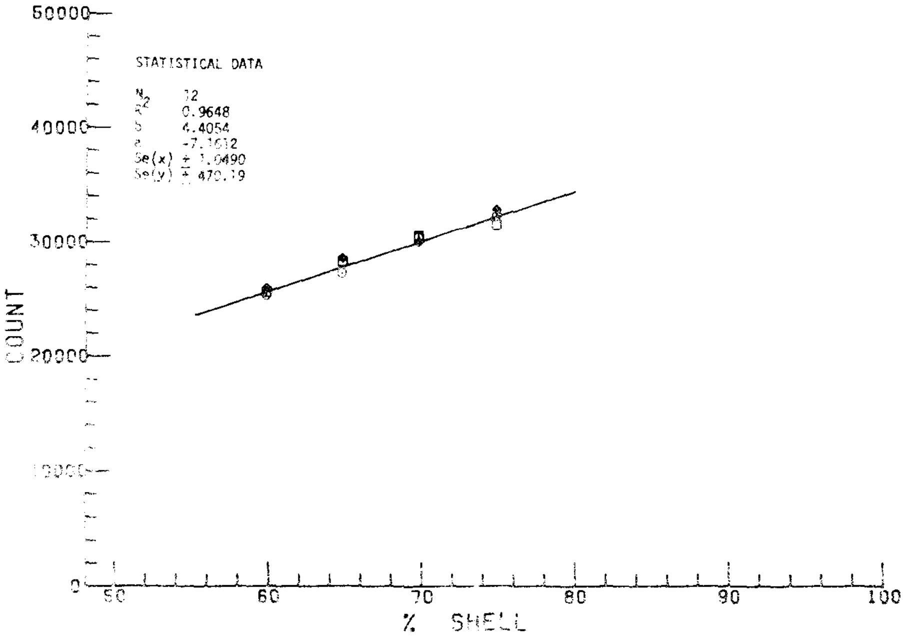
Lake Charles Sand-Reef Shell Calibration Curve
(10-2-10----12% Moisture Added)

FIGURE 37



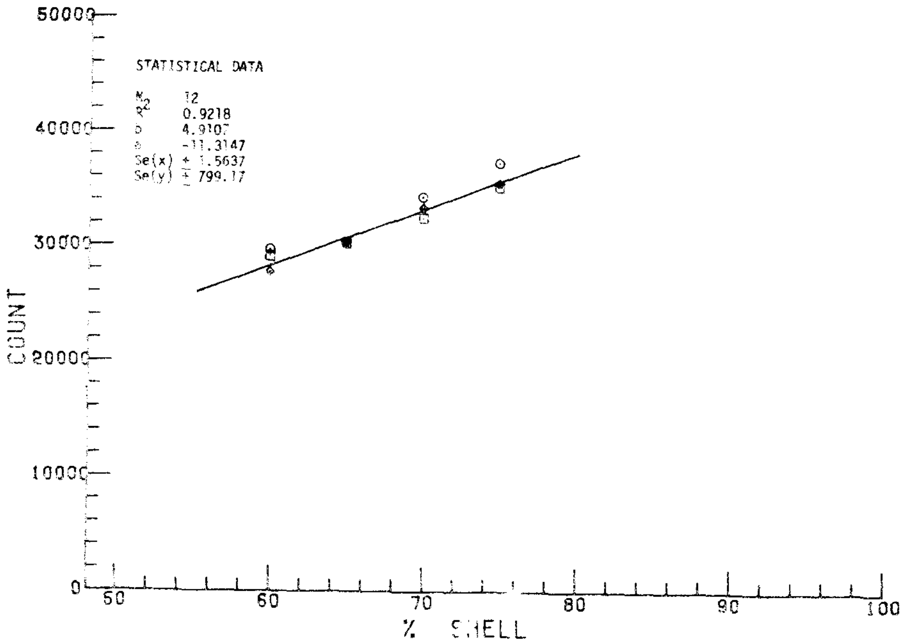
Lake Charles Sand-Clam Shell Calibration Curve
(10-2-10----12% Moisture Added)

FIGURE 38



Ottawa Sand-Reef Shell Calibration Curve
(10-2-10----12% Moisture Added)

FIGURE 39



Ottawa Sand-Clam Shell Calibration Curve
(10-2-10----12% Moisture Added)

FIGURE 40

TABLE 2

RESULTS OF ACTIVATION OF SEPARATE MATERIALS (DRY)
(NUCLEAR COUNTS)

SANDS

OTTAWA SAND	LAKE CHARLES SAND	RACELAND SAND
315	945	6,316
255	1,049	6,525

SHELLS

REEF SHELL	CLAM SHELL
27,392	28,563
28,181	28,924
27,794	28,560

All samples tested at 5-minute activation-1-minute decay-5-minute count

TABLE 3

ANALYSIS OF SANDS AND SHELLS

Mineralogy and Gradation of Sands

	Raceland Sand	Lake Charles Sand	Ottawa Sand
Crystalline Quartz, %	85.1	85.6	99.0
Cherts, %	14.0	13.9	1.0
Other Silicates, %	0.7	0.5	
Organic, %	0.2		

Sieve No.		Percent Passing	
10	100	100	100
20	100	100	98
30	100	100	1
40	97	100	0
200	2	18	0
Specific Gravity	2.63	2.63	2.62

Wet Chemistry Analysis of Shell

	Clam	Reef
Loss, %	44.26	43.94
Silicon Dioxide, %	1.34	0.72
Iron and Aluminum Oxides, %	1.18	1.18
Calcium Oxides, %	52.08	54.52
Sulfur, % (Dioxide)	0.23	0.08
Magnesium Oxide, %	0.25	0.12
Insolubles, %	00.40	00.26

TABLE 4

NUCLEAR COUNTS OF NEUTRON
ACTIVATED SAND-SHELL MIXTURES
(OVEN DRIED)
TEN MINUTE ACTIVATION-TWO MINUTE DECAY-TEN MINUTE COUNT

PERCENT SHELL	10	20	40	60	65	70	75	85
RACELAND SAND REEF SHELL	13,053 13,122 12,462	15,441 16,186 16,136	22,670 22,536 22,894	30,586 29,535 30,795	32,341 31,686 31,792	32,427 31,678 33,121	35,091 35,026 33,348	39,135 38,553 39,201
RACELAND SAND CLAM SHELL	13,826 13,441 13,696	17,079 17,506 17,310	25,437 23,313 24,273	32,867 31,243 31,731	31,449 35,230 32,240	37,586 34,884 35,629	37,204 38,384 37,477	41,757 42,049 41,740
LAKE CHARLES SAND REEF SHELL	4,938 4,339 5,044	7,932 7,975 8,127	16,838 15,640 15,465	23,093 24,522 24,472	27,497 27,205 26,915	30,895 30,823 30,392	32,080 32,254 33,096	36,316 35,289 36,112
LAKE CHARLES SAND CLAM SHELL	4,503 4,361 3,996	9,144 7,602 7,997	16,404 16,852 16,333	26,739 23,722 21,839	26,876 29,156 28,297	32,841 32,963 32,891	35,337 35,331 34,812	40,905 40,184 40,400
OTTAWA SAND REEF SHELL	3,223 3,260 4,063	6,322 6,711 6,171	13,586 13,940 14,218	21,419 22,336 20,970	27,436 24,188 24,138	28,836 28,543 28,137	27,978 28,050 29,110	34,608 35,545 36,278
OTTAWA SAND CLAM SHELL	2,788 3,847 3,328	7,577 7,941 6,708	13,605 13,536 13,678	23,404 22,895 23,088	25,562 26,539 29,729	29,963 29,697 31,091	33,577 32,111 33,099	34,858 35,708 34,677

TABLE 5

NUCLEAR COUNTS OF NEUTRON
ACTIVATED SAND-SHELL MIXTURES
(OVEN DRIED)
FIVE MINUTE ACTIVATION-ONE MINUTE DECAY-FIVE MINUTE COUNT

PERCENT SHELL	10	20	40	60	65	70	75	85
RACELAND SAND REEF SHELL	7,583 7,655 7,128	9,083 9,757 9,587	13,497 13,293 13,451	17,969 17,640 18,541	19,323 19,774 19,017	20,897 20,883 20,682	22,159 21,896 21,719	23,740 22,587 23,158
RACELAND SAND CLAM SHELL		11,456 11,471 12,090	17,802 15,855 16,525	22,214 21,958 22,152	23,109 25,930 23,668		26,304 26,432 26,671	30,196 30,832 30,254
LAKE CHARLES SAND REEF SHELL	3,121 2,903 2,930	4,797 4,800 4,494	9,358 9,149 9,101	14,279 14,900 15,193	16,659 16,770 16,550	18,952 19,201 18,092	20,629 19,705 19,803	23,435 23,534 22,737
LAKE CHARLES SAND CALM SHELL	3,557 3,624 3,345	6,314 5,760 5,976	11,179 11,277 11,578	20,764 19,443 17,525	18,759 19,103 19,906	21,377 21,987 21,657	23,800 23,455 25,472	27,170 26,991 26,970
OTTAWA SAND REEF SHELL	2,568 2,789 3,111	4,781 4,968 4,946	10,200 10,098 10,267	16,035 16,507 15,352	20,349 18,279 17,862	20,511 20,049 19,282	21,075 20,792 21,427	25,203 24,980 26,145
OTTAWA SAND CLAM SHELL	2,299 3,032 2,844	4,934 6,037 5,071	10,298 11,958 10,349	17,637 19,064 17,499	19,613 20,042 21,060	22,084 22,657 23,512	24,281 23,966 23,672	26,502 26,447 25,916

TABLE 6

NUCLEAR COUNTS OF NEUTRON
ACTIVATED SAND-SHELL MIXTURES

TEN MINUTE ACTIVATION-TWO MINUTE DECAY-TEN MINUTE COUNT ---- 4% MOISTURE ADDED

PERCENT SHELL	60	65	70	75
RACELAND SAND REEF SHELL	28,805 29,445 28,909	30,864 31,692 30,444	33,539 32,819 32,441	36,812 36,747 36,304
RACELAND SAND CLAM SHELL	29,643 30,937 28,919	31,119 32,896 33,297	33,871 33,755 33,448	36,317 39,225 38,529
LAKE CHARLES SAND REEF SHELL	24,008 23,877 24,594	27,504 26,701 25,973	33,223 32,749 31,893	33,290 32,986 31,503
LAKE CHARLES SAND CLAM SHELL	27,478 26,986 26,142	27,523 28,485 27,134	31,778 31,283 31,835	34,513 37,097 35,797
OTTAWA SAND REEF SHELL	21,968 21,458 22,532	26,080 25,985 22,481	26,928 28,017 28,910	30,839 30,409 31,822
OTTAWA SAND CLAM SHELL	23,422 24,077 23,600	26,237 27,329 27,376	27,874 31,250 31,219	35,523 34,867 34,414

TABLE 7

NUCLEAR COUNTS OF NEUTRON
ACTIVATED SAND-SHELL MIXTURES

TEN MINUTE ACTIVATION-TWO MINUTE DECAY-TEN MINUTE COUNT ---- 8% MOISTURE ADDED

PERCENT SHELL	45	50	55	60	65	70	75
RACELAND SAND REEF SHELL	22,415 22,132 22,565	24,402 24,439 25,042	25,341 26,112 25,499	27,539 28,170 29,001	29,552 29,466 28,818	31,966 30,416 30,964	34,256 34,889 34,392
RACELAND SAND CLAM SHELL				29,498 32,080 29,888	32,718 30,960 33,926	35,883 35,452 37,207	37,322 40,744 37,658
LAKE CHARLES SAND REEF SHELL				26,008 24,725 25,131	27,410 28,368 28,292	30,703 31,180 30,930	32,117 30,913 31,752
LAKE CHARLES SAND CLAM SHELL				25,314 26,114 25,744	28,614 30,115 28,990	32,504 33,524 33,010	34,093 34,265 33,510
OTTAWA SAND REEF SHELL				28,556 25,639 24,898	25,430 27,771 26,973	30,047 29,413 29,476	30,543 32,257 31,643
OTTAWA SAND CLAM SHELL				26,814 28,582 29,498	28,508 28,251 29,692	33,537 32,188 32,897	35,213 33,937 35,510

TABLE 8

NUCLEAR COUNTS OF NEUTRON
ACTIVATED SAND-SHELL MIXTURES

TEN MINUTE ACTIVATION-TWO MINUTE DECAY-TEN MINUTE COUNT ----12% MOISTURE ADDED

PERCENT SHELL	60	65	70	75
RACELAND SAND REEF SHELL	29,282 28,113 28,999	31,607 31,192 31,825	32,769 33,736 34,790	35,218 35,436 35,939
RACELAND SAND CLAM SHELL	32,361 32,681 32,428	35,602 36,555 35,888	39,701 37,753 39,959	41,122 40,108 44,306
LAKE CHARLES SAND REEF SHELL	26,580 24,834 27,068	30,667 28,670 28,639	31,001 31,452 30,583	32,673 32,960 33,322
LAKE CHARLES SAND CLAM SHELL	31,410 28,872 29,438	34,800 32,338 33,336	35,002 38,809 38,168	39,089 41,420 39,685
OTTAWA SAND REEF SHELL	25,628 25,228 25,858	28,279 27,257 28,580	30,557 30,411 29,984	31,417 32,215 32,830
OTTAWA SAND CLAM SHELL	29,037 29,472 27,572	30,127 30,254 30,256	32,403 34,232 33,301	35,068 37,136 35,331