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UNIFORMITY OF MIXING OF BITUMINOUS CONCRETE BY NEUTRON ACTIVATION ANALYSIS

A THESIS

Presented to

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by

Paul King Howard

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UNIFORMITY OF MIXING OF BITUMINOUS CONCRETE BY NEUTRON ACTIVATION ANALYSIS

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SUMMARY

The objective of this study is to determine the mineral filler content of asphaltic concrete samples by neutron activation analysis. Hveem stability and aggregate fineness modulus will be determined for comparisons to determine uniformity of mixing.

Asphaltic concrete, mixed for various lengths of time, was sampled and tested for mixing uniformity. Three samples were drawn from each discharged batch and each sample was evaluated as to its aggregate fineness modulus, Hveem stability, and mineral filler content.

Mineral filler content of samples was determined by neutron activation analysis of the calcium-49 within the mineral filler. A series of samples with known mineral filler content were irradiated, counted for gamma emissions within a certain energy range, and a mineral filler content versus count graph was drawn. Samples collected were then irradiated, counted, and their mineral filler content was determined from this graph.

The relationship between mineral filler and calcium-49 count was not determined to the degree of accuracy necessary for predicting unknown mineral filler content. For this and other reasons it is concluded that activation analysis using the Van de Graaff Accelerator with a beryllium target does not appear to be a feasible method for determining the mineral filler content for bituminous concrete mortar samples.

It may be concluded from the data collected that mixing times of 30 seconds or greater have no effect on the uniformity of mixing as measured by Hveem stability, fineness modulus or calcium count. However, differences from batch to batch are very significant for Hveem stability

and less significant for fineness modulus and calcium count. Position and interactions have no effect on the uniformity of mixing with the exception of the interaction of mixing time and position for Hveem stability which is significant at the 5 per cent level. No reason can be assigned to this difference, and it is assumed to be chance error.

Research in the uniformity of mixing of bituminous concrete at various mixing times should be continued using mineral filler dispersion as a measure of uniformity of mixing. However, a higher and more stable neutron flux is required for further research.

CHAPTER I

INTRODUCTION

General Remarks

Consumption

In 1961, 74 per cent of all domestic shipments of petroleum asphalts were used for paving products (1). This amounted to more than 15 million short tons and was used to construct many miles of new roads and streets as well as resurface and patch old facilities. The construction and maintenance required an expenditure of millions of dollars at all levels of government. As with any expenditure of public funds, attention was closely directed to quality of product received.

Measures of Quality

The measures of quality of interest for bituminous concrete mixtures are stability, durability, flexibility, resistance to skidding, and workability. Techniques are available at the design stage to insure mixtures meeting quality specifications, but the specifications are often difficult to achieve in the field with present construction practices. The difficulties arise in three areas: proportioning the mix constituents; mixing the constituents to uniformity; and placing the mix on the roadway.

Scope of Research

This research has been concerned with the problem of mixing the bituminous concrete constituents to obtain uniformity. Activation analysis was used to determine the dispersion of mineral filler throughout the mix as a measure of uniformity of mixing. Stability of the mix and aggregate fineness modulus were determined and compared to the dispersion results.

Testing Methods to Determine Mixing Uniformity

Background

All bituminous pavement mix design methods are predicated on the assumption that field production methods will produce a uniform mixture. With increasing use of bituminous materials in highway construction it is becoming more and more important to develop a simple procedure for testing for uniformity of mix. Producers of bituminous concrete mixes are vitally interested in the mixing time required to produce a uniform mixture because of the highly competitive marketing of their products as reflected by cost of product.

Present Methods

Methods now available for testing a batch for uniformity require determination of mix properties at various points within the batch. Comparison among the points indicates degree of mixing of the batch. The mix properties used are stability, gradation and asphaltic cement content.

Stability

Stability, defined as resistance to displacement, is one of the most important properties required of a bituminous mixture (2). Stability depends on the interlocking or internal friction of the aggregate particles and the cohesion of the cementing agent. There are many methods for measuring stability, such as the Hubbard-Field stability test, unconfined-compression test, Marshall test, Hveem stabilometer test, and triaxial-compression test. While each of these tests indicates a stability, each test also indicates effects particular to the individual test method.

Gradation

Gradation is the particle size distribution of the aggregate. It is expressed as per cent by weight of aggregate passing through a series

of sieves of standard sized openings. The gradation of the aggregate in a bituminous concrete sample can be determined only after the asphaltic cement has been extracted from the aggregate.

Gradation can also be expressed as aggregate fineness modulus in order to reduce the amount of data required to describe a sieve analysis. To find the fineness modulus, the percentage of material coarser than a standard series of sieves is calculated, and the sum of these percentages divided by 100 is the fineness modulus. By this definition, different gradations may produce similar fineness modulus; however, differences in fineness modulus always indicate differences in gradation.

Asphaltic Cement Content

Asphaltic cement content is expressed as the per cent of asphaltic cement by weight of total mix. The standard method for determining asphaltic cement content involves weighing the mix sample, extracting the asphaltic cement with trichloroethane, and drying and weighing the free aggregate. The difference thus determined is weight of asphaltic cement.

Uniformity of Mix

Comparisons among positions within a batch using stability, fineness modulus, or asphaltic cement content indicate degree of mixing or uniformity of mix for the batch. Uniformity of mixing from batch to batch is determined by comparing the above variables for several batches.

Mineral Filler Content

The dispersion of mineral filler throughout the mix, in addition to the method described above using stability and fineness modulus, was used to determine uniformity of mixing. Dispersion of mineral filler was measured by comparing mineral filler content as determined by activation

analysis. Comparisons were made among the various positions, mixing times, and batches.

The mineral filler, in this case a powdered limestone produced by the Georgia Marble Company, contained essentially the same constituents as portland cement. Earlier research at Georgia Tech on portland cement concrete used calcium-49, produced by bombardment of calcium-48, as the element for activation analysis (3). Investigation revealed that this isotope, present in mineral filler, was also suitable for this research.

Hot-Mix Plants

Plant designs are of two types: continuous or batch. The continuous hot-mix plant maintains a steady input of aggregate, asphaltic cement and mineral filler to the mixer with a steady output of bituminous concrete. The hot-mix batch plant receives the input in a batch, mixes the constituents, and dumps the output in a batch.

The batch plant is most common of the types of mixers used for bituminous concrete production. For this reason, the batch plant was chosen to be sampled in this project.

The plant sampled was a Cedar Rapids G-40, a 4000 pound batch plant, located just south of Tyrone, Georgia, on State Route 74. The plant was owned by the McIntosh Paving Company. The plant is shown in Figure 1.

Because of the large amount of dust created by a hot-mix batch plant it was not possible to use a radioactive tracer method to evaluate uniformity of mixing of the mineral filler. Neutron activation was chosen as an alternative method.

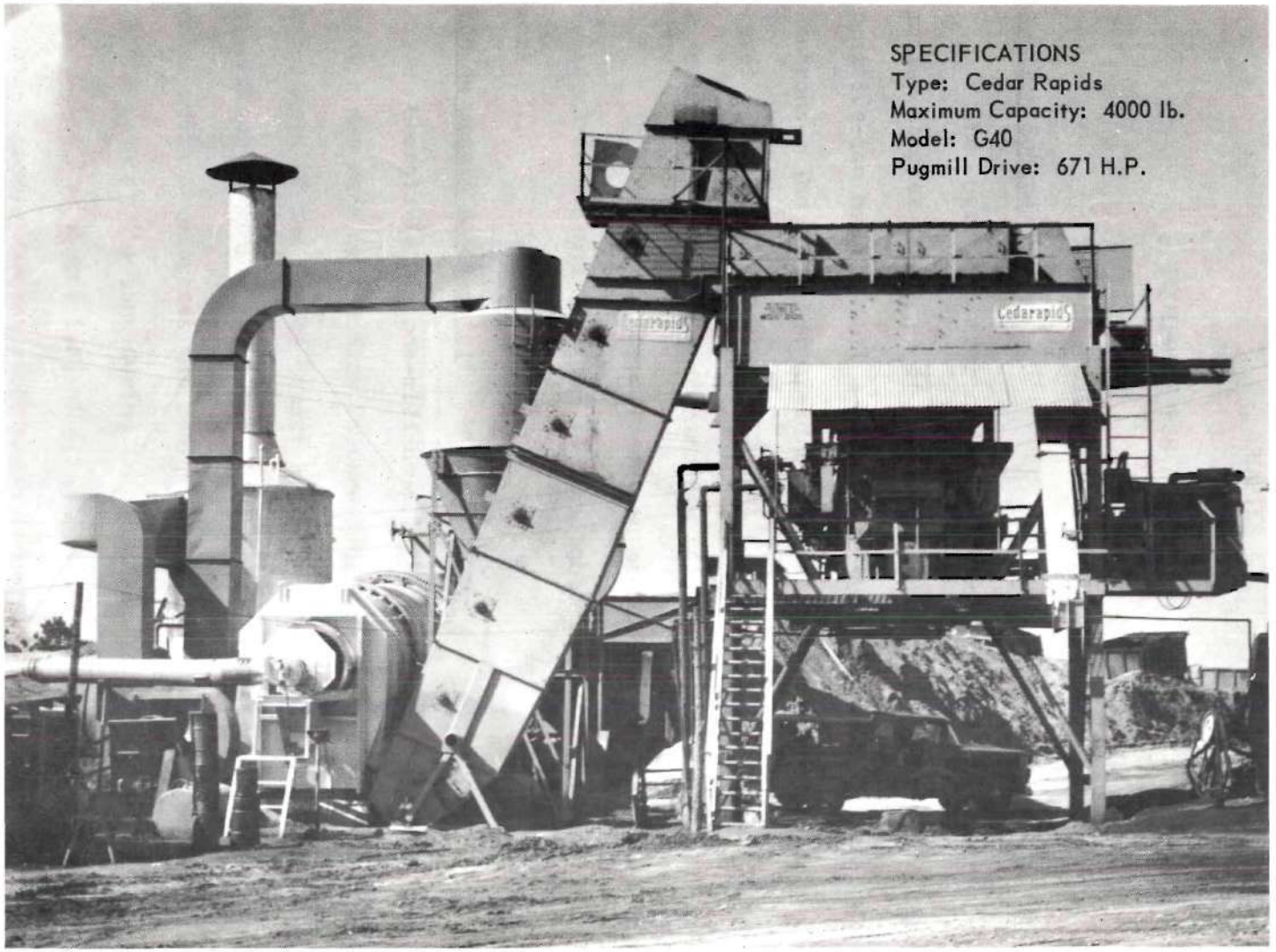

Figure 1. Specifications of Mixer for McIntosh Paving Company, Tyrone, Georgia.

to the beryllium target where neutrons are produced by the $Be^{9}(d,n)Be^{10}$ reaction.

Neutron Moderator

The neutron moderator is a mass of paraffin which surrounds the beryllium target. Its success as a moderator depends on the high concentration of hydrogen atoms which have a very high collision cross section for neutrons. An access tube in the moderator positions the mortar specimen several centimeters below the target where the thermal neutron flux is approximately 5×10^{6} thermal neutrons per square centimeter per second. A schematic diagram of the neutron moderator is shown in Figure 2.

Analysis Equipment

Scintillation Detector

The thermal neutrons, on striking the sample, activated the calcium-48 to produce calcium-49 in the mineral filler of the sample. The activity of the calcium-49 decayed by emitting gamma radiation.

The gamma radiation emitted by the activated bituminous concrete mortar specimens was detected by a pair of thallium activated sodium iodide crystals coupled to photomultiplier tubes. Basically, the stepwise operations of this system are: the production of light in the crystal by incident gamma radiation which is proportional to the energy of the radiation, the conversion of the light by a photocathode into an electrical pulse which is similar to the light output in both magnitude and duration, and the preamplification of the electrical pulse by a factor of about 100 in the photomultiplier tube. This system is stable and is recognized as the most efficient method for detecting gamma radiation.

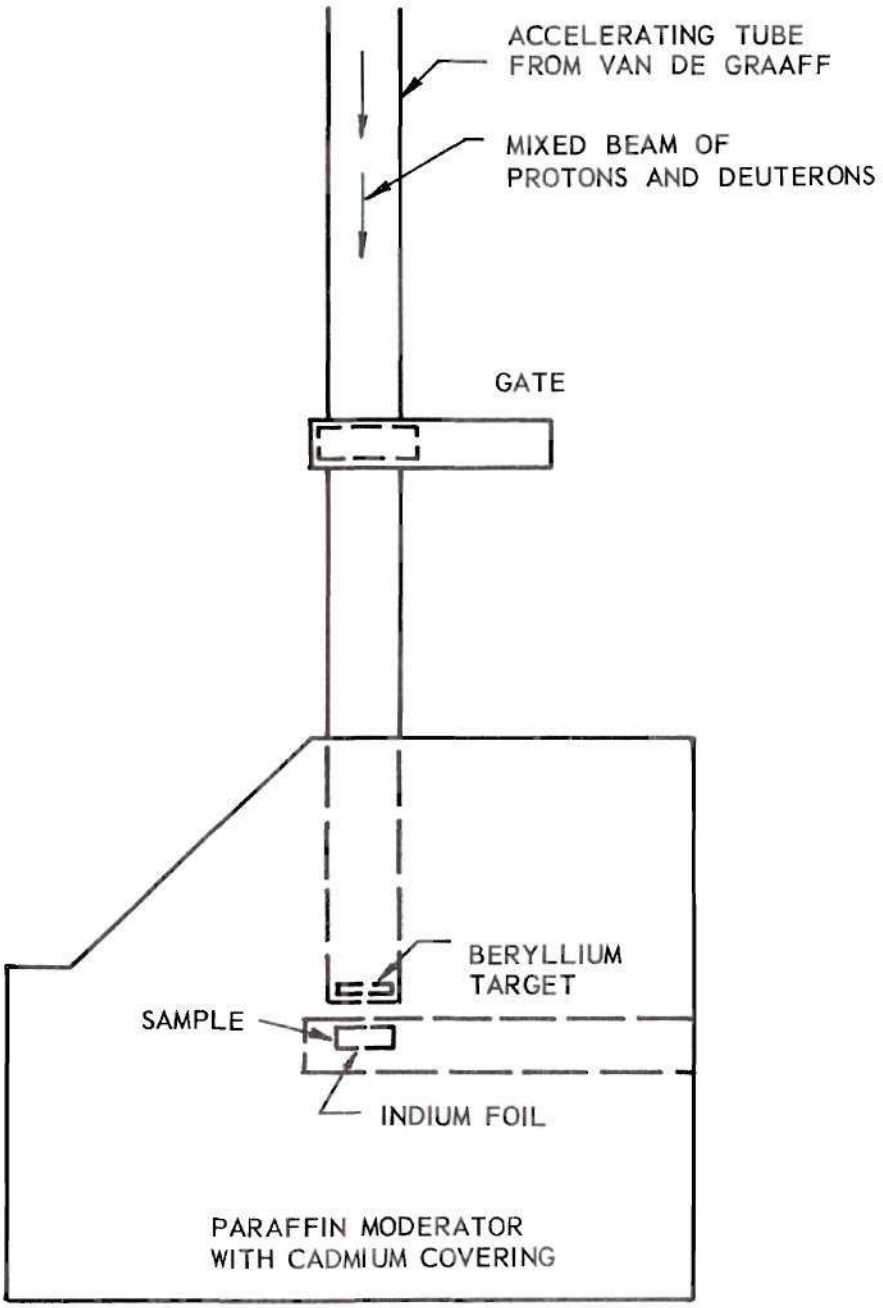

Figure 2. Schematic Diagram of the Thermal Neutron Moderator in the Van de Graaff.

Pulse-Height Analyzer

The purpose of the Penco 100 Channel Pulse-Height Analyzer was to count radiation and store the counts according to the energy of the individual gamma ray which produced the count. The electrical pulses from the photomultiplier tubes were combined by a coupler and fed into a linear amplifier. This amplifier, after amplification, fed the pulse to the analyzer. After storage in the 100 channel memory unit of the analyzer, the counts were printed by channel number on roll paper by the Victor adding machine.

Scintillation Spectrometer

The detection and counting equipment described above, when integrated into one system as shown in the schematic diagram of Figure 3 and the picture in Figure 4, is usually referred to as a scintillation spectrometer. Its usefullness lies in its ability to detect and record gamma radiation with a thorough knowledge of the energy of the radiation.

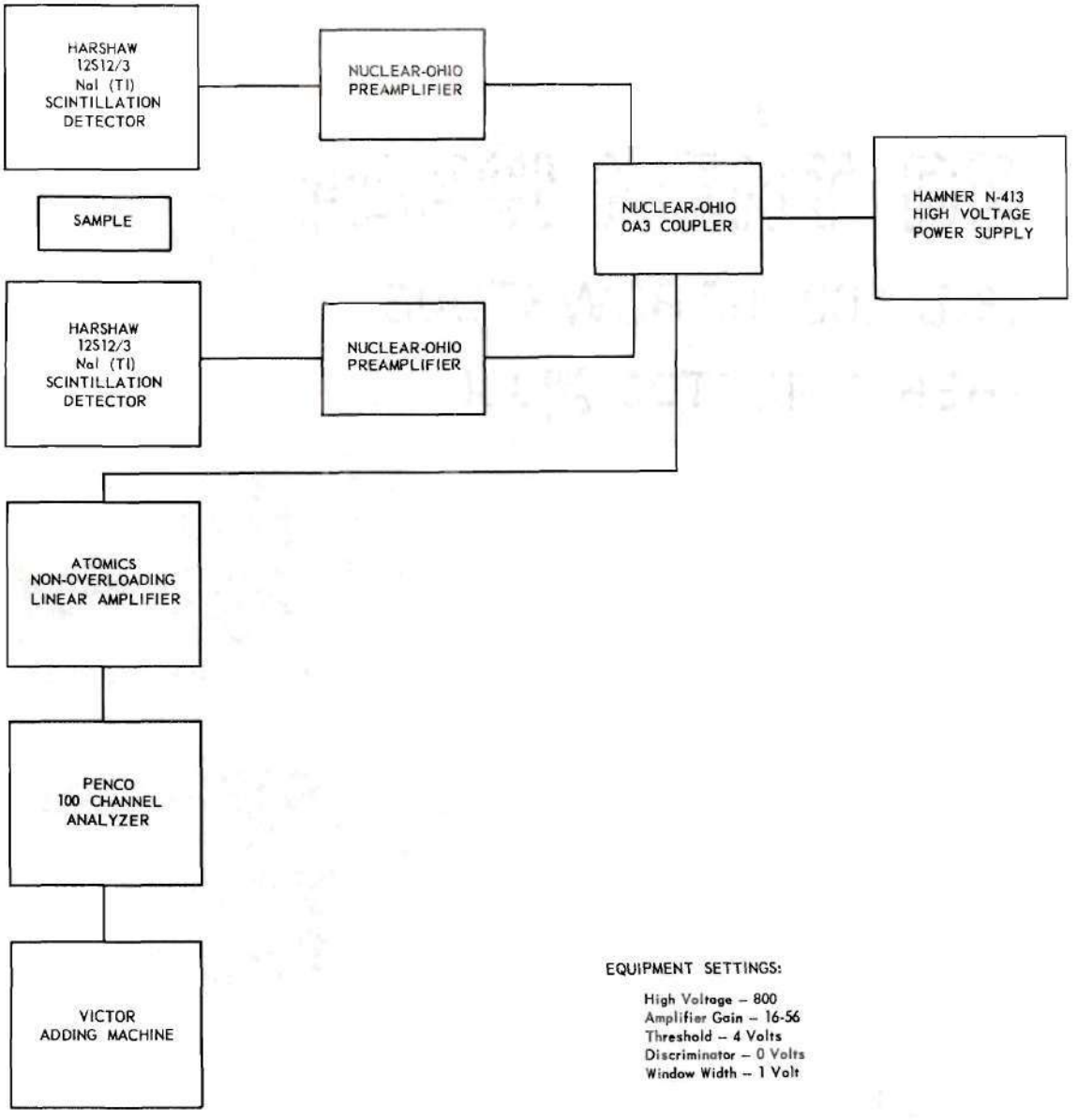

Figure 3. Schematic Diagram of Scintillation Spectrometer.

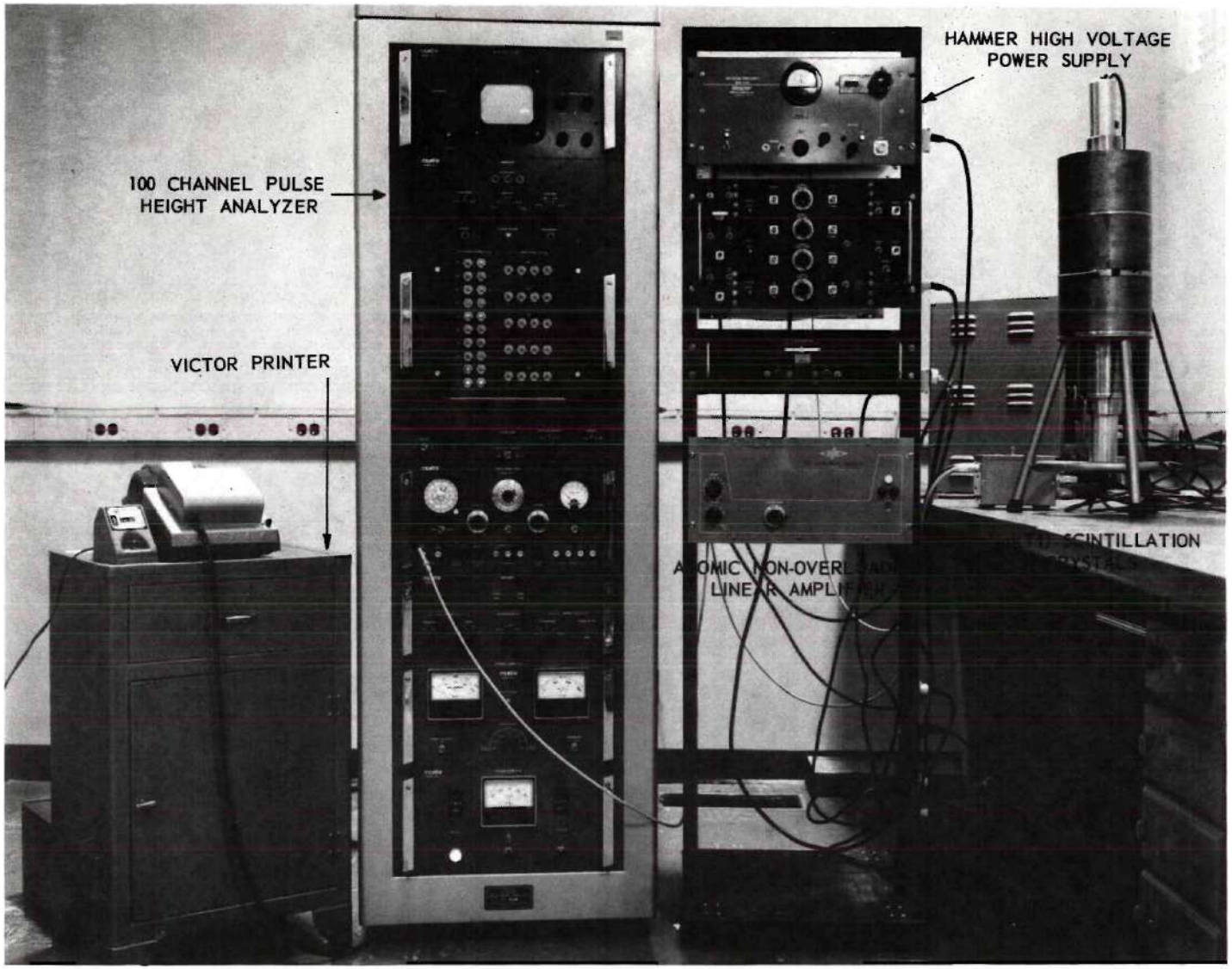

Figure 4. Scintillation Spectrometer.

CHAPTER III

TESTING PROGRAM

General Information

Cooperation of several bituminous concrete producers in the vicinity of Atlanta was secured for the sampling of their hot-mix batch plants. The criteria for plant selection was that the plant be scheduled to produce pavement of bituminous concrete containing mineral filler during late spring or early summer and that the plant have no unusual or unique characteristics. Because of the time limitation the number of hot-mix batch plants sampled was reduced to one.

The plant chosen was a Cedar Rapids G-40 Asphalt Hot-Mix Batch Plant owned by McIntosh Paving Company at Tyrone, Georgia. The batch capacity of the plant is 4000 pounds. A photograph and specifications of the plant are given in Figure 1.

Mix proportions used by the plant during the field sampling are given in Table 1 and the chemical analyses of these materials are shown in Table 2, as furnished by the State Highway Department of Georgia.

Because of the design of the Cedar Rapids G-40, samples could not be drawn directly from the mixer. As an alternative, timed batches were dumped into trucks where three samples were taken representative of three different points in the mixer.

Design of the Experiment

The experiment was chosen to consist of five different mix times: 30, 45, 60, 90, and 180 seconds. Each mix time was repeated twice.

Table 1. Proportions Used in Cedar Rapids G-40 Hot-Mix Plant, McIntosh Paving Company

"E" Type Surface Mix as Specified by State Highway Department of Georgia

Sieve Sizes		Per Cent by Weight of Total Mix	Weight (Pounds)
Passing	Retained		
3/4	1/2	13.3	533
1/2	1/4	38.3	1533
1/4	Pan	39.3	1571
Mineral Filler		2.6	103
Asphaltic Cement, AC-6		6.5	260
Total		100.0	4000

Table 2. Chemical Analysis of Mineral Filler and Aggregate

Chemical Compound	Per Cent by Weight
Mineral Filler	
Mineral Products Division, Georgia Marble Co., Tate, Georgia	
CaO	51.14
SiO_2	3.72
Al_2O_3	0.08
Fe_2O_3	0.20
SO_3	0.06
MgO	2.71
Ins. Res.	4.10
Loss on Ign.	42.24
K_2O	0.00
Na_2O	0.05
$AsNa_2O$	0.05
Aggregate	
Tyrone Rock Products Co., Quarry No. 1, Tyrone, Georgia	
CaO	0.03
SiO_2	95.08
Al_2O_3	1.58
Fe_2O_3	1.50
SO_3	0.03
MgO	0.74
Ins. Res.	91.54
Loss on Ign.	0.68
K_2O	0.31
Na_2O	0.00
$AsNa_2O$	0.20

An agreement with the commercial producer of bituminous concrete required that sampling be completed during one morning's operations and without interruption of plant operation. It was, therefore, impossible to sample with true replication. As an alternative both mix times and samplings for each mix time were randomized so that the batches sampled were nested within mix times. A total of 60 samples were taken from the Cedar Rapids G-40.

Each sample taken was evaluated for Hveem stability, fineness modulus, and mineral filler content by neutron activation. Throughout the sampling and testing every effort was made to eliminate systematic errors.

Processing of Samples

Collecting of Samples

Samples collected in the field were returned to the laboratory for processing and testing. No effort was made to maintain sample temperature during transport.

The samples were placed in a 300° F oven for 4 hours prior to processing. The samples were then mixed in a Hobart laboratory mixer for one minute to insure uniformity within each sample and sectioned and quartered into the portions required for the various tests.

Hveem Stability Samples

Specimens for the Hveem stability test required 1200 grams of mix. They were constructed and treated according to the recommendations of the Asphalt Institute (5). Stability specimens are shown in Figure 5.

Fineness Modulus

Fineness modulus determination required 1000 grams of mix. The asphaltic cement was extracted in a centrifuge using trichloroethane.

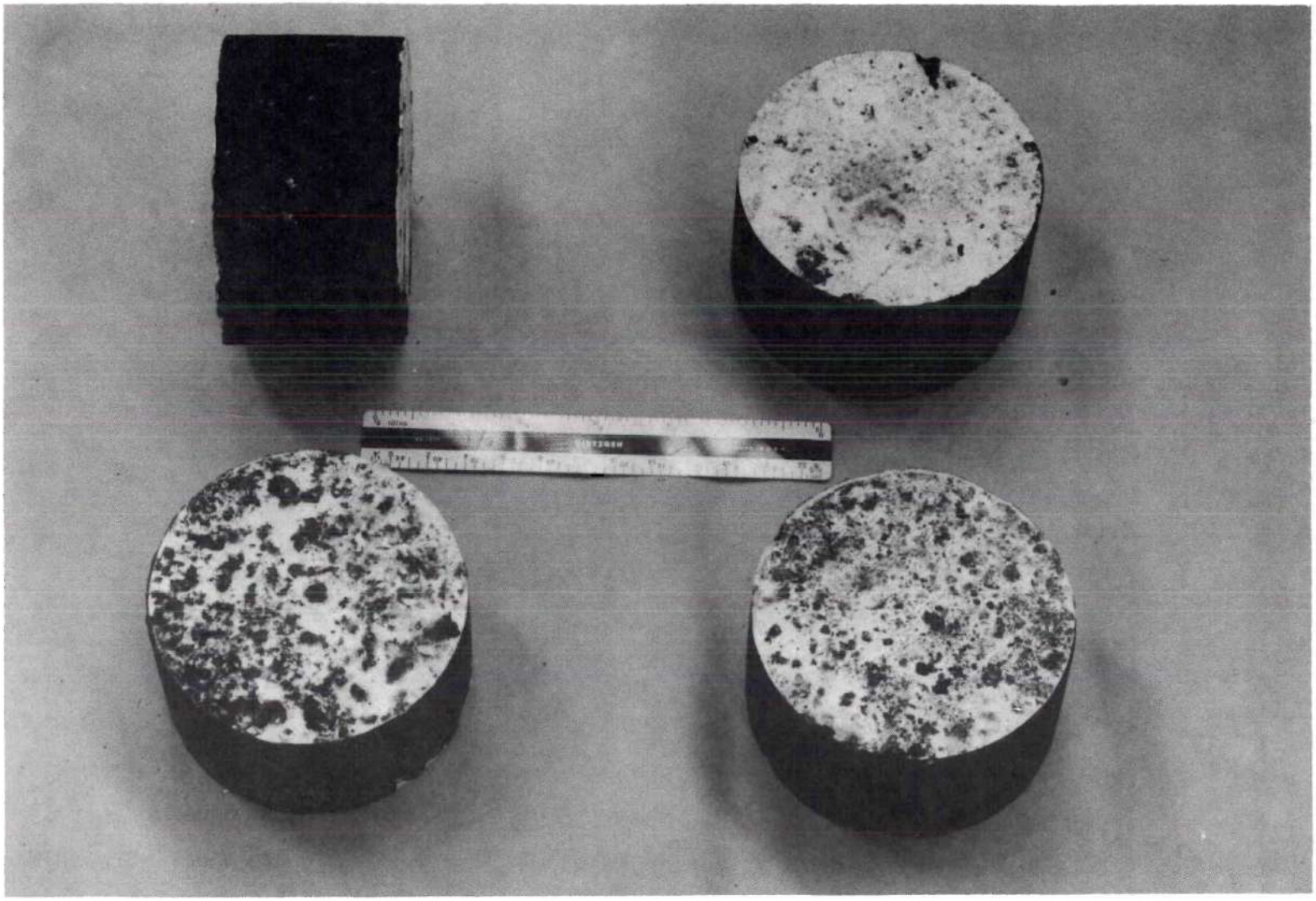

Figure 5. Bituminous Concrete Speciments Used to Evaluate Stability.

Gradation was determined by sieve analysis. Both extraction and sieve analysis were performed in accordance with the standards of the American Association of State Highway Officials (6).

Mineral Filler

Specimens for the determination of mineral filler dispersion were required to be so small that larger aggregates had to be removed before the specimens were constructed. About 50 grams of hot mix were screened through a number 4 separation sieve. The passing material was then compacted by hand into 3/4-inch-diameter by 3/4-inch-high polystyrene containers using a 5/8-inch steel mandrel. Figure 6 shows the prepared mortar specimens.

In order to determine the amount of mineral filler passing the separation sieve, six samples containing known amounts of mineral filler and aggregate passing the number 200 sieve were prepared. Each sample was then passed through the number 4 separation sieve. The materials retained on the separation sieve and the materials passing the separation sieve were then extracted and subjected to gradation analysis. The results of the gradation analyses allowed computation of the percentage of minus 200 material passing the separation sieve. With the assumption that mineral filler and minus 200 aggregate dispersed similarly in the mix, 45 per cent of the mineral filler passed the separation sieve.

Testing of Samples

The Hveem stability test was chosen as a test for strength because it theoretically eliminates the effect of cohesion of the bituminous cement (7). The test required the use of a Hveem stabilometer in conjunction with a standard controlled-rate loading machine as shown in Figure 7. Test conditions were as recommended by the Asphalt Institute (5).

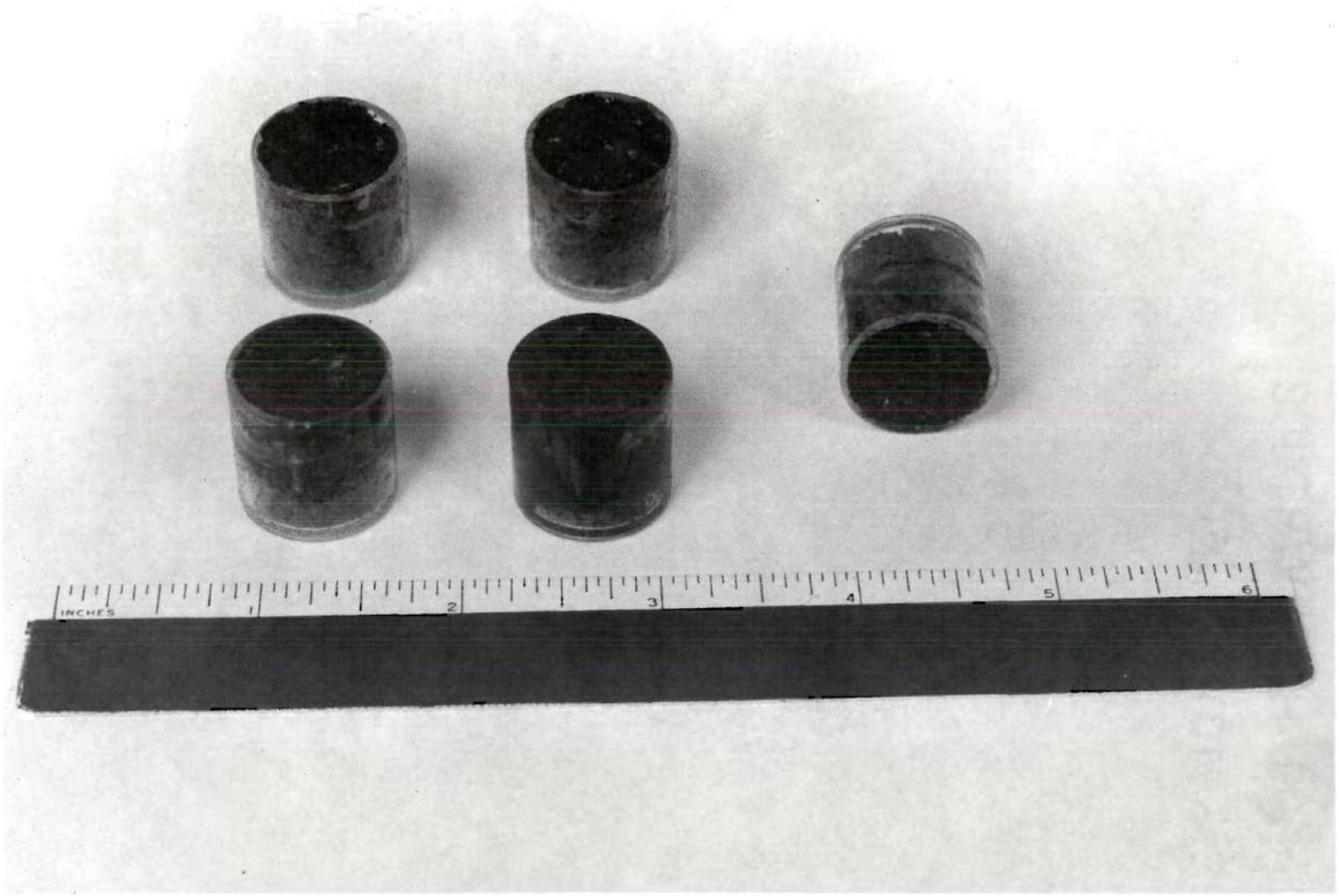

Figure 6. Bituminous Concrete Mortar Specimens Used to Evaluate Mineral Filler Content.

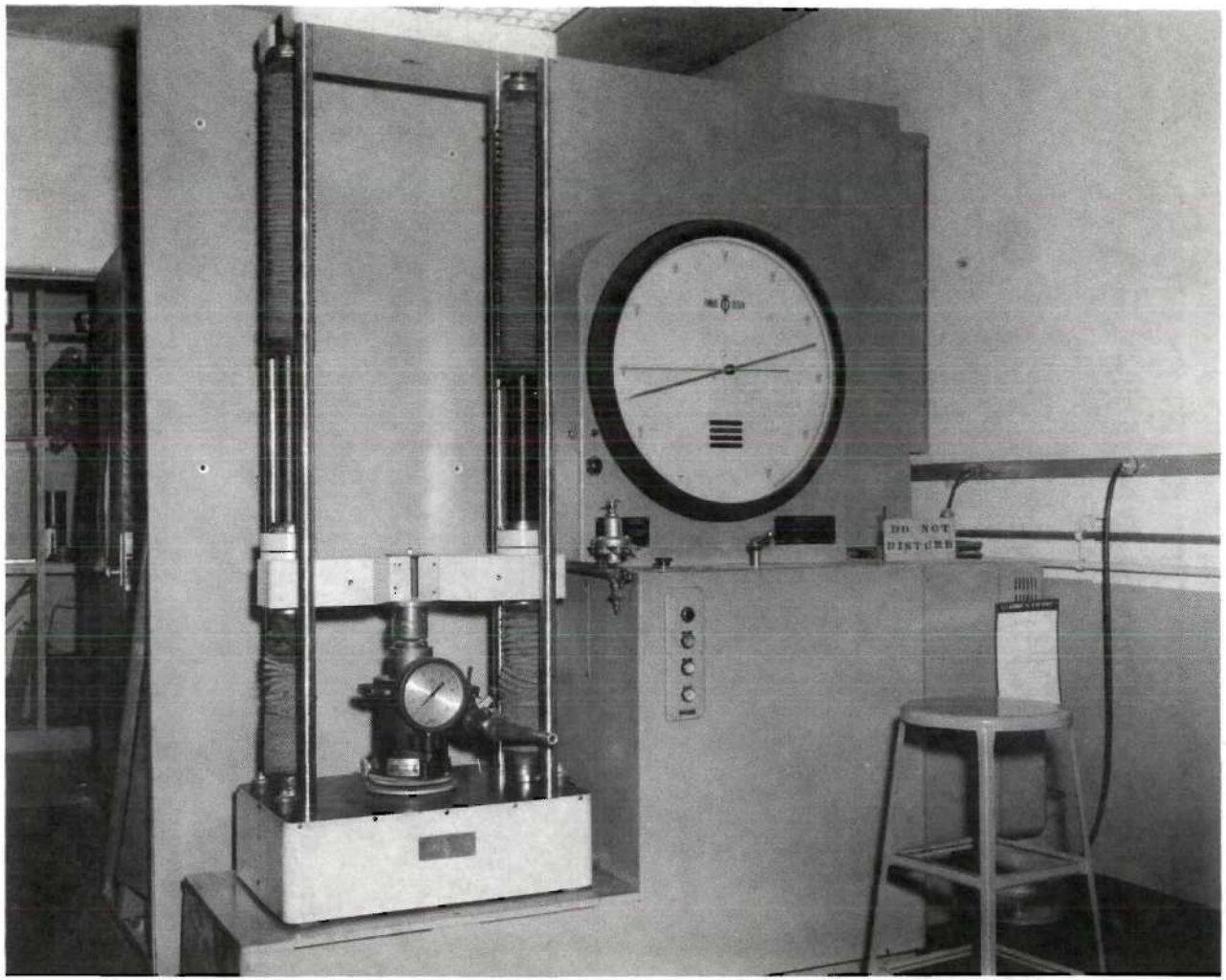

Figure 7. Hveem Stabilometer and Controlled-Rate Loading Machine.

Determination of Mineral Filler Content

The mineral filler used throughout this research was a crushed limestone furnished by the Mineral Products Division, Georgia Marble Company, Tate, Georgia. Results of a chemical analysis of the mineral filler and the aggregate are presented in Table 2.

As noted in Table 2, the mineral filler contains 51.14 per cent calcium oxide. The normal range of mineral filler used in bituminous concrete is from 2 to 6 per cent. In view of these low figures, it was deemed desirable to calculate a sample size by first choosing an amount of calcium to be present in the sample. This choice was 0.1 grams of calcium and was based on the work of a previous research project dealing with portland cement concrete (3). The sample size was then calculated on the basis of the chosen amount of calcium. This calculation indicated that a 3/4-inch-diameter by 3/4-inch-high sample was required.

At the beginning of the neutron activation phase of the work the scintillation spectrometer (100 channel analyzer, crystals, and amplifier) was aligned and calibrated. The calibration placed the 3.07 mev (million electron volts) pulse, which was emitted by calcium-49, in channel 72. During each subsequent run using the spectrometer a plot of energy versus channel number was made as a check for system stability. A standard radioactive sample of cobalt-60 was used to locate the channels receiving the 1.17, 1.33 and 2.50 mev pulses. These points were then plotted as shown in the curve of Figure 8.

Figure 9 is the plot of a decay study made prior to activation analysis to determine the peak range of calcium-49. The range indicated was channels 66 through 76 as shown by the area between the 0-5 minute curve and the 30-35 minute curve in that region. The decay study also

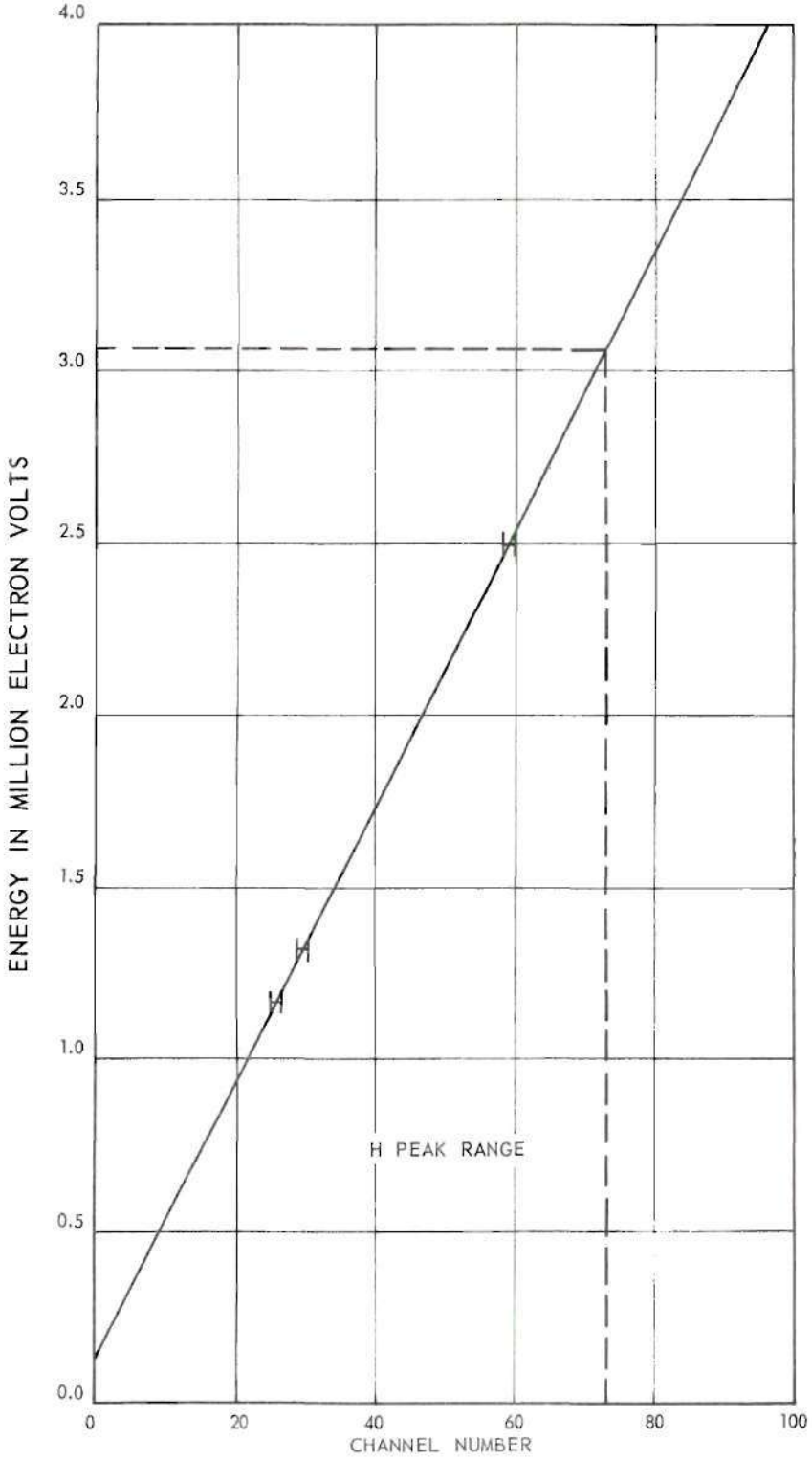

Figure 8. Calibration Curve for the Scintillation Spectrometer Using Co^{60}.

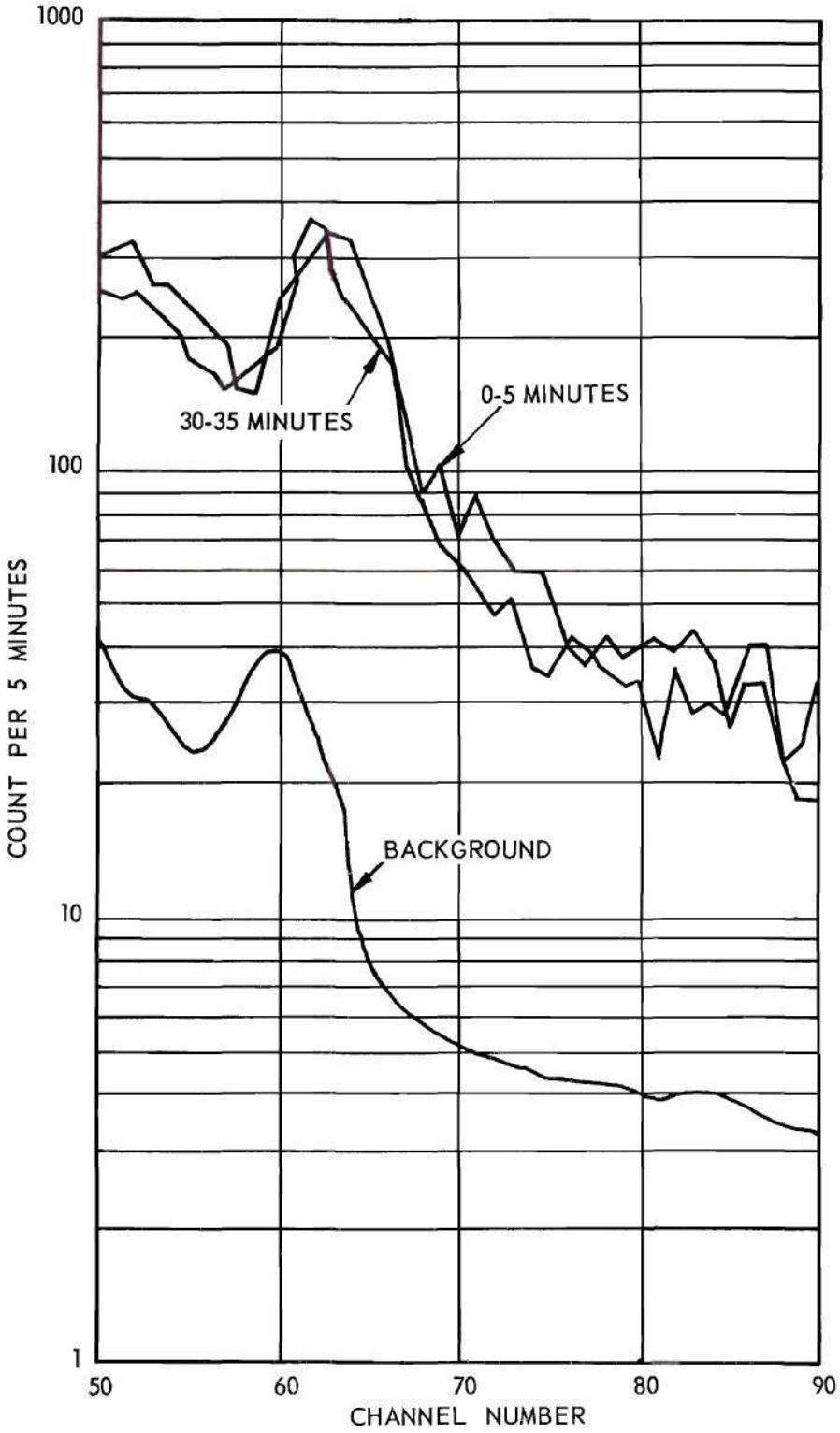

Figure 9. Decay of 3.07 MEV Peak in Channels 66 Through 76 of Calcium-49 in Bituminous Concrete Mortar Specimen.

indicated that the Ca^{49} peak was positioned on the tail of a Na^{24} peak which accounted for the majority of the counts in the channels where the Ca^{49} peak would occur. The Na^{24} peak was known to have a half-life of 15 hours or more. In order to divorce the counting statistics from the influence of the Na^{24} peak, two counts were taken on each activation sample. The first 5 minute count was started 90 seconds after irradiation. The second count was started 30 minuted later. Since the half-life of the Na^{24} peak was much longer than the half-life of the Ca^{49} peak, the 30 minute interval had negligible effect on the count of the sodium peak while the activity of the calcium peak was reduced by more than 90 per cent. This logic was the basis for choosing a 30 minute interval. The sample count was taken as the difference between the total counts in channels 66 through 76 for the first and second counting periods.

A study of the decay of the total count in the 10 channels was made to insure that the counts recorded included the Ca^{49} 3.07 mev decay. The half-life of this 3.07 mev gamma is 8.9 ± 0.2 minutes (8). The decay of the 10 channels had a half-life of 8.6 minutes as indicated in Table 3 and Figure 10.

Each sample was irradiated for 10 minutes in the Van de Graaff. During this period the Van de Graaff beam varied in intensity. To eliminate the effects of the variation from the sample count, the neutron flux was monitored and the count adjusted to the value it would have been had the flux intensity been constant. The monitoring was accomplished using small pieces of indium foil of known weight. The foil was irradiated along with the asphaltic cement concrete mortar sample and both were counted at the same time (3). The foil count was then normalized to a standard weight

Table 3. Decay Study of 3.07 MEV Peak in Channels 66 Through 76

Counting Time* (Minutes)	Count
0- 5	2263
9-14	1060
18-23	512
27-33	257

*Counting time started 90 seconds after the end of irradiation.

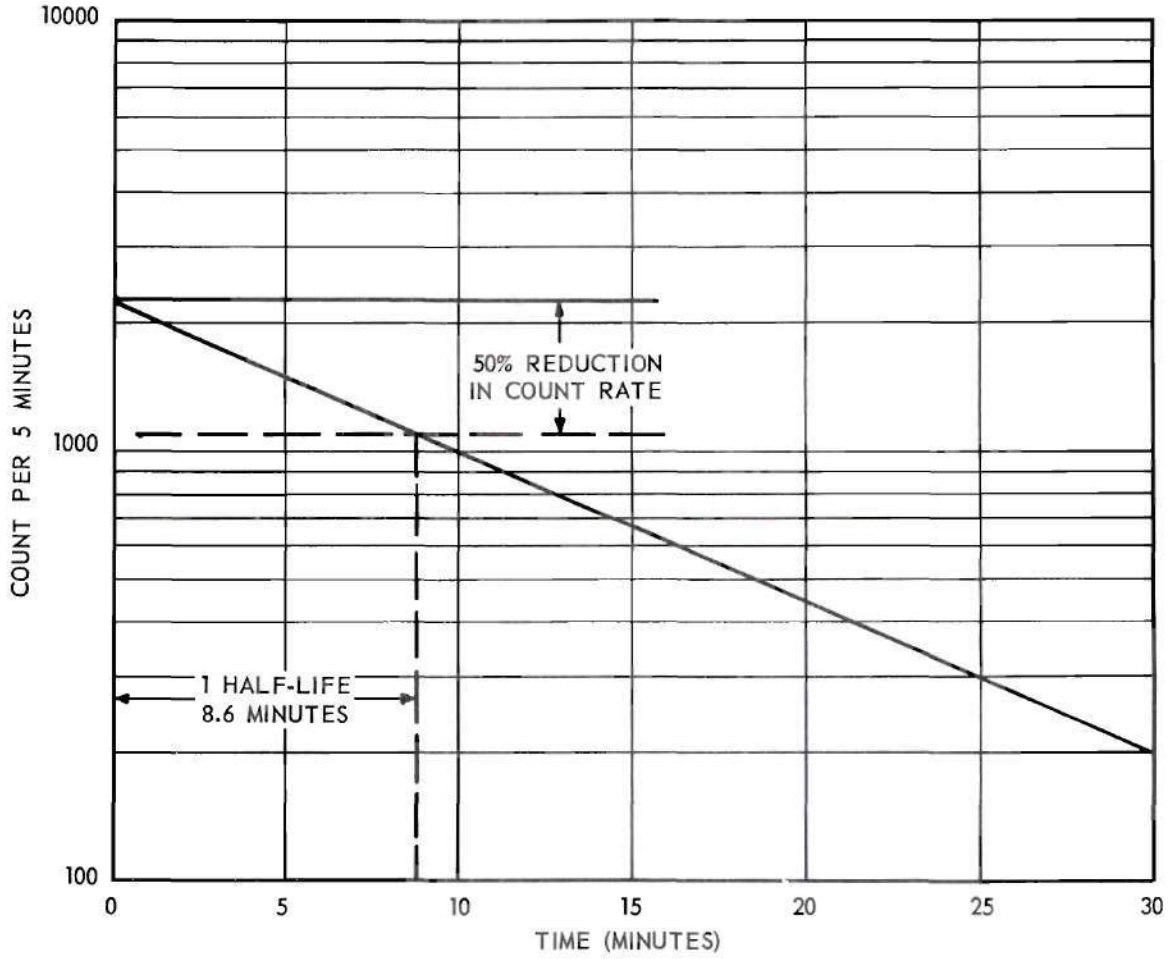

Figure 10. Half-Life Determination of 3.07 MEV Peak in Channels 66 Through 76.

and count. The sample count could then be normalized to the adjusted foil count. An example of count normalization is given in Appendix A.

Bituminous concrete mortar samples containing known amounts of mineral filler were prepared for activation analysis. These samples were used as standards to relate mineral filler content to the calcium-49 count. The relationship between the normalized standard counts and the mineral filler contents was established by means of a regression line computed by the method of least squares. This relationship is shown in Figure 11. A sample correlation coefficient and 95 per cent confidence limits were also computed and are shown. The sample correlation coefficient, r, was found to be 0.420. This number is used as an approximate measure of association between the observed data and the calculated line. This coefficient was accepted as an indication that a linear relationship does exist between mineral filler content and count rate, however, the scatter of the data prevented an accurate determination of that relationship.

The scatter of the observed counts of the samples containing known amounts of mineral filler was responsible for both the low correlation coefficient and the wide confidence limits. This scatter was probably the result of several factors as follows:

1. Instability of neutron production. Neutron production using a beryllium target is very sensitive to extraneous material coating condensed or burned onto the target surface. As the Van de Graaff beam uncontrollably wandered across the target surface, clean or unbombarded portions of the surface had higher neutron production rates than contaminated portions. Furthermore, both the beam energy and the beam current were subjected to uncontrolled variation which affected the neutron production rate.

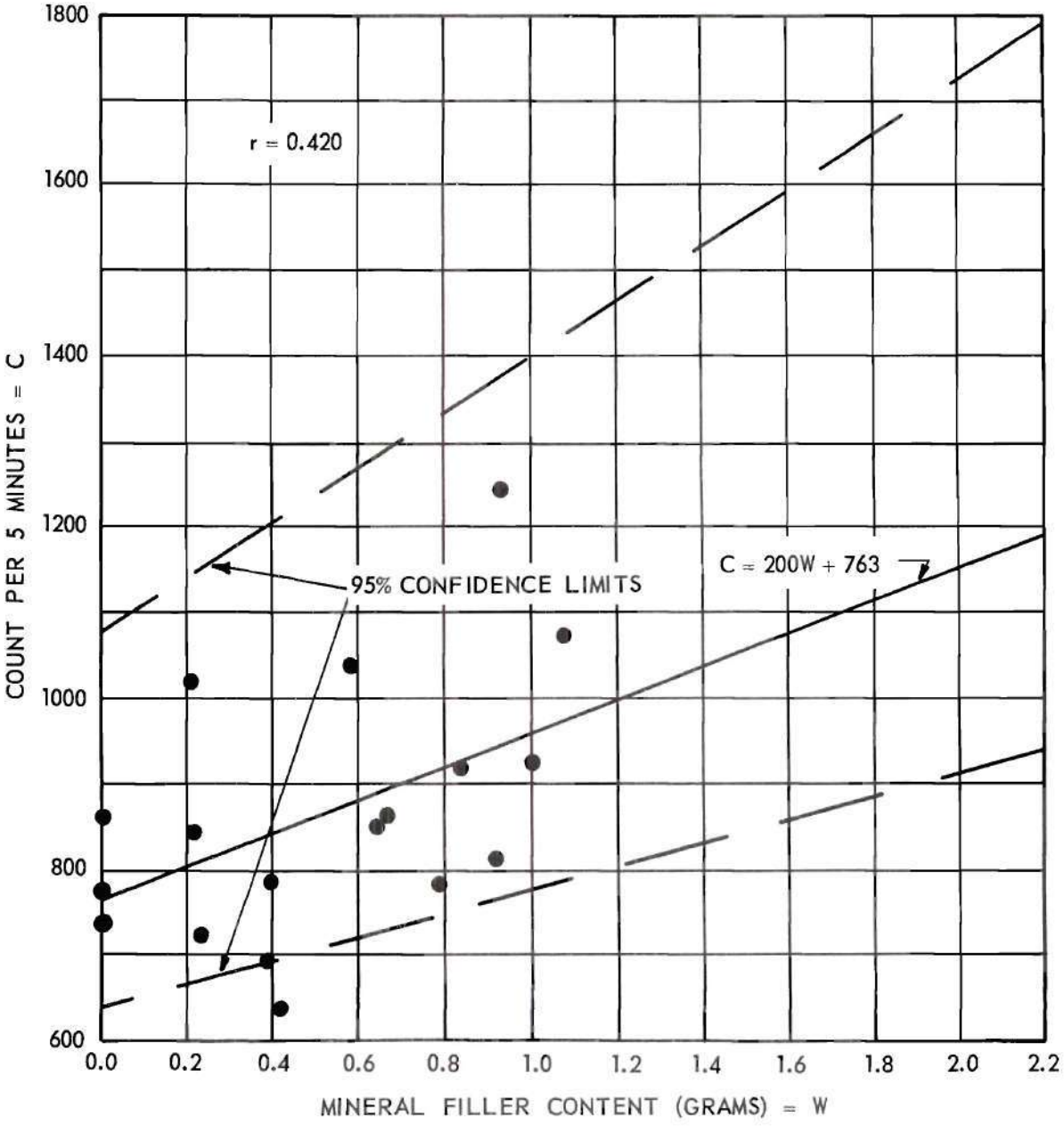

Figure 11. Mineral Filler Content Versus Count Chart.

2. Low mineral filler content. The standard samples used to develop the curve of Figure 11 contained from zero to 1.1 grams of mineral filler. At the low end of this range the counting statistics were very poor. For example, when the calcium-49 count was 800, the estimate of the standard deviation was the square root of 800 or 28.

3. Nonuniform standards. Regardless of the care with which the standard samples were constructed, there exists the possibility that the constituents of the samples were segregated. The effects of such segregation would be a scattering of results as was obtained.

4. Low thermal neutron flux. Approximate calculations indicated that the thermal neutron flux at the sample irradiation point was about 5×10^6 thermal neutrons per square centimeter per second. This low flux coupled with the low calcium content would produce errant counts.

The normalized counts of the samples were then used to enter the chart of Figure 11 to determine values for the mineral filler content.

Analysis of Variance

Analysis of variance was used to analyze the data collected. This procedure would allow comparison of certain quantitative physical characteristics as influenced by controllable variables. The quantitative physical characteristics are referred to as dependent variables and the controllable variables are independent.

The dependent variables were mineral filler content, stability, and fineness modulus. Both mineral filler content and fineness modulus (gradation) appeared to be independent variables because mineral filler and aggregates were placed in the mix in controlled amounts. This apparent independence was not real because the mineral filler and aggregates

entered the mixing apparatus in segregated batches. The point values of mineral filler content and fineness modulus were, therefore, dependent on the uniformity of mixing.

The selected independent variables were mixing time, position in the mixer, and batch. Batch was analogous to replication and differed only in that batches were nested within mixing time because of restrictions on field sampling.

Computations for the sum of squares, degrees of freedom, and expected mean squares were performed on a computer (9). The general mathematical model for the variance was as follows:

$$X_{ijk\alpha} = y + T_i + B_{(i)j} + P_k + (TP)_{ik} + (BP)_{(i)jk} + \varepsilon_{(ijk)\alpha}$$

This general model was modified to agree with the various sampling levels. Table 4 gives the primary variables and subscript levels of the model for the general case.

Analysis of variance techniques have become common tools of research because they allow rigorous analysis of data with statements of probability accompanying conclusions. These techniques are thoroughly explained in texts dealing with statistics (10) (11).

Table 4. Primary Variables for Analysis of Variance

Factor	Abbreviation	Subscript	No. Levels	Model
Mix Time	T	i	5	Fixed
Batch	B	j	2	Random
Position	P	k	3	Fixed

CHAPTER IV

RESULTS

Mineral Filler Content

Utilizing the unadjusted counts of Table 5, the form of computation exemplified in Appendix A and the chart in Figure 9, the determination of the mineral filler content of the samples subjected to activation analysis was possible. Table 6 gives the results of this process. These results contain a preponderance of zero values of mineral filler content. For this reason, it was felt that analysis of variance of the mineral filler content data would produce no useable information. The high incidence of zeros in the values might be attributed to any one or a combination of several effects as follows:

1. Of the points used to derive the curve of Figure 11, very few were in the mineral filler content range of the unknown samples. This produced a curve of low sensitivity at the low mineral filler content end.

2. Aside from the 55 per cent loss of mineral filler from the unknowns during the separation process, there was some unexplained difference between the standard activation samples and the unknown activation samples.

3. The 55 per cent loss of mineral filler from the unknowns left the unknown activation samples with insufficient mineral filler to produce a statistically reliable calcium-49 count.

However, the normalized calcium-49 counts in Table 7 were subjected to analysis of variance as shown in Table 8. This analysis indicates that mix time, batch, position and interactions of these variables have no

significant effect on the calcium-49 count at the 5 and 1 per cent levels of significance.

Inspection of Table 7 indicates that the calcium-49 count of the field sampling produced a range from 468 to 990 normalized counts per 5 minutes. This wide range coupled with the analysis of variance discussed in the previous paragraph indicates that the variations in data due to effects of the independent variables and their interactions are very small compared to the variations due to effects of uncontrolled variables.

Aggregate Fineness Modulus

Table 9 gives the values of aggregate fineness modulus of the samples collected during the experiment. Results of the analysis of variance are shown in Table 10.

From Table 10 it may be noted that none of the independent variables or their interactions have significant effect on the aggregate fineness modulus at the 5 and 1 per cent levels.

Hveem Stability

Table 11 shows the stabilities obtained by the Hveem method from the samples collected. Table 12 shows the computed analysis of variance for Hveem stability.

Table 12 indicates that the interaction of mixing time and position was significant at the 5 per cent level.

In Table 12 the hypothesis that the different batches do not affect Hveem stability is rejected. The effect of different batches was significant at the 10 per cent level in the analyses of variance for calcium-49 count and fineness modulus as shown in Tables 8 and 10, respectively.

While the 10 per cent level of significance was not considered sufficiently rigorous for the purpose of comparison it is given here to indicate continuity of the batch effect throughout the results. These results show the basic non-repeatibility of uniformity of mixing from batch to batch, regardless of mixing time or position in the mixer. Mixing time and position are not significant.

CHAPTER V

SUMMARY OF RESULTS AND CONCLUSIONS

Summary of Results

Results obtained for mineral filler content, fineness modulus, and Hveem stability are as follows:

1. Mineral Filler Content: The relationship between mineral filler and calcium-49 count was not determined to the degree of accuracy necessary for predicting unknown mineral filler contents. The analysis of variance for the calcium-49 count indicated that all main and interaction effects for the mixer studied were not significant.

2. Aggregate Fineness Modulus: Mixing time, batch, position, and interactions of these variables had no significant effect on the fineness modulus for the mixer studied.

3. Hveem Stability: For the mixer studied, differences from batch to batch were very significant for Hveem stability. All other main and interaction terms were not significant with the exception of significance at the 5 per cent level for the interaction of mix time and position. No reasons can be assigned to this difference and it is assumed to be a chance error.

Conclusions

1. Activation analysis using the Van de Graaff Accelerator with a beryllium target does not appear to be a feasible method for determining the mineral filler content for bituminous concrete mortar samples.

However, the author feels that a more stable and higher neutron flux, as will be produced by the reactor now under construction at Georgia Tech or as can be produced by neutron generators, will render the method feasible.

A routine testing method for mineral filler content of bituminous concrete would require, among other things, portable testing equipment. For this reason activation analysis is not a feasible method for routine testing. Radioactive neutron sources, such as the radium-beryllium mixture, appear to be a logical choice for neutron production. However, if the source is large enough to produce sufficient neutrons, the shielding requirements of the source render it non-portable. The author concludes that activation analysis is not a feasible method for routine determination of mineral filler content of bituminous concrete mortar samples.

2. It may be concluded from the data collected that mixing times of 30 seconds or greater have no effect on the uniformity of mixing as measured by Hveem stability, fineness modulus or calcium count. However, differences from batch to batch are very significant for Hveem stability and less significant for fineness modulus and calcium count. Position and interactions have no effect on the uniformity of mixing with the exception of the interaction of mixing time and position for Hveem stability which is significant at the 5 per cent level. No reason can be assigned to this difference, and it is assumed to be chance error.

3. Research in the uniformity of mixing of bituminous concrete at various mixing times should be continued using mineral filler dispersion as a measure of uniformity of mixing. However, a higher and more stable neutron flux is required for further research. The author does not believe that research using the reactor under construction at Georgia Tech would

produce an economical routine testing method. However, such research would produce information of great benefit to state highway departments, producers of bituminous concrete, and mixing equipment manufacturers.

APPENDIX

APPENDIX A

EXAMPLE CALCULATIONS FOR NORMALIZING CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS AND DETERMINING MINERAL FILLER CONTENTS

Sample Number	Indium Foil Data			Sample Count			
	Foil Count(Nt) Per 5 Minutes	Foil Weight (mg)	Nt Per 100 Mg	First Count Channels 66-76	Second Count Channels 66-76	Sample Count (Difference)	Sample Count for Nt=15000
325	10,776	81.5	8,782	2,446	1,573	873	990

Sample Number	Mineral Filler Content				
	Sample Weight (Grams)	Container Weight (Grams)	Net Sample Weight (Grams)	Weight Mineral Filler* (Grams)	Mineral Filler Content (Grams Filler Per Gram Mix)
325	12.125	1.870	10.255	1.160	0.113

*See Figure 9.

APPENDIX B

DATA AND ANALYSIS OF VARIANCE

Table 5. Unadjusted Calcium-49 Count Per 5 Minutes of Bituminous Concrete Mortar Specimens From Tyrone Plant

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	509	414	886	798	815
		2	567	443	1011	738	781
	2	1	906	461	505	873	896
		2	712	514	597	807	812
	3	1	835	724	523	617	449
		2	797	570	488	732	914
2	1	1	1091	611	912	740	703
		2	613	565	768	501	457
	2	1	573	615	1077	682	675
		2	509	660	935	645	358
	3	1	1032	583	746	482	766
		2	860	628	892	698	445

APPENDIX B (Continued)

Table 6. Mineral Filler Content of Bituminous Concrete Mortar Specimens in Grams Mineral Filler Per Gram Mix From Tyrone Plant

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	0	0	0.072	0.055	0
		2	0	0	0	0	0
	2	1	0.102	0	0	0.113	0.019
		2	0	0	0	0.059	0.016
	3	1	0.040	0	0	0	0
		2	0	0	0	0	0.060
2	1	1	0.077	0	0.059	0.057	0.016
		2	0	0	0	0	0
	2	1	0	0	0.101	0	0
		2	0	0	0.045	0.009	0
	3	1	0.082	0	0	0	0.071
		2	0.070	0	0.033	0	0

APPENDIX B (Continued)

Table 7. Normalized Calcium-49 Count Per 5 Minutes of Bituminous Concrete Mortar Specimens From Tyrone Plant

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	662	531	879	870	753
		2	676	471	738	744	738
	2	1	963	562	573	990	800
		2	705	548	649	876	796
	3	1	847	727	636	651	687
		2	760	632	709	755	882
2	1	1	927	643	891	883	799
		2	728	549	762	562	493
	2	1	664	697	974	713	716
		2	648	685	853	786	479
	3	1	929	606	706	655	906
		2	902	670	823	720	468

APPENDIX B (Continued)

Table 8. Analysis of Variance for Normalized Calcium-49 Count Per 5 Minutes of Bituminous Concrete Mortar Specimens From Tyrone Plant

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests		
				F	$F_{0.05}$	$F_{0.01}$
Mixing Time	241,515.00	4	60,378.75	1.988	5.19	11.4
Batches (Within Time)	151,893.66	5	30,378.73	2.477*	2.53	3.70
Position	4,367.10	2	2,183.55	0.141	4.46	8.65
Time x Position	123,600.38	8	15,450.05	1.080	3.07	5.06
Batch x Position (Within Time)	143,029.76	10	14,302.98	1.166	2.16	2.98
Residual	367,881.92	30	12,262.73			
Total	1,032,287.8	59				

*Significant at the 10 per cent level.

APPENDIX B (Continued)

Table 9. Aggregate Fineness Modulus, Tyrone Plant

Batch	Position in Discharge	Mixing Time (Seconds) 30	45	60	90	180
1	1	3.33	3.32	3.59	3.45	3.19
	2	3.21	3.22	3.51	3.33	3.40
	3	3.43	3.21	3.38	3.47	2.98
2	1	3.50	3.39	3.26	3.65	3.29
	2	3.46	3.26	3.41	3.66	3.23
	3	3.52	3.26	3.40	3.68	3.34

APPENDIX B (Continued)

Table 10. Analysis of Variance for Fineness Modulus, Tyrone Plant

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests		
				F	$F_{0.05}$	$F_{0.01}$
Mixing Time	0.385	4	0.096	3.00	5.19	11.4
Batches (Within Time)	0.160	5	0.032	2.64*	3.33	5.64
Position	0.00965	2	0.00482	0.562	4.1	7.56
Time x Position	0.0687	8	0.00858	0.709	3.07	5.06
Batch x Position (Within Time)	0.121	10	0.0121			
Total	0.744	29				

*Significant at the 10 per cent level.

APPENDIX B (Continued)

Table 11. Hveem Stability, Tyrone Plant

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	28	48	28	53	55
		2	28	37	44	57	48
	2	1	42	38	42	48	45
		2	30	48	39	50	45
	3	1	33	44	52	48	51
		2	37	31	52	48	43
2	1	1	36	26	35	35	49
		2	28	27	49	44	44
	2	1	47	33	37	39	54
		2	43	31	34	36	57
	3	1	46	36	48	34	42
		2	36	31	45	30	44

APPENDIX B (Continued)

Table 12. Analysis of Variance for Hveem Stability, Tyrone Plant

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests		
				F	$F_{0.05}$	$F_{0.01}$
Mixing Time	1,182.43	4	295.61	1.26	5.19	11.4
Batches (Within Time)	1,169.50	5	233.9	9.64*	2.53	3.70
Position	43.23	2	21.62	0.21	4.46	8.65
Time x Position	840.27	8	105.03	3.11**	3.07	5.06
Batch x Position (Within Time)	337.50	10	33.75	1.39	2.16	2.98
Residual	728.00	30	24.27			
Total	4,300.93	59				

*Significant at the 1 and 5 per cent levels.

**Significant at the 5 per cent levels.

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