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NUCLEAR DENSITY GAUGE MONITORING OF ASPHALT CONCRETE COMPACTION

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NUCLEAR DENSITY GAUGE MONITORING OF ASPHALT CONCRETE COMPACTION

INTRODUCTION

Several times during the past 20 years the Transportation Research Board (TRB) has surveyed the State highway agencies, the Canadian provincial highway agencies, and selected county, city, and other agencies, on their use of nuclear moisture and density gauges. These surveys showed by the early 1970's the nuclear gauges had gained general acceptance for specification control of soils and soil-aggregates (bases and subbases). Acceptance of the gauges for use on bituminous concrete proceeded more slowly, but now in the 1980's that use is becoming widespread.

To confirm this last trend and to establish current density control practice, TRB Committee A2H01, Instrumentation Systems, Principles, and Applications, prepared a questionnaire for another survey. The questionnaire was distributed by TRB early in 1983, and responses were received from 49 State highway agencies, five Canadian provincial highway agencies, and four other agencies. (Because the latter four agencies were each the only one of a given type of organization to respond to the survey and because they made little or no use of nuclear gauges, their responses have not been included in the tabulations and discussion that follow. Committee A2H01 appreciated their efforts in responding to the questionnaire.) This report presents the results of the survey. The Questionnaire is included as an appendix.

Brand names, manufacturers and models are mentioned in this report for informational purposes only. The Transportation Research Board does not endorse products or manufacturers.

DENSITY MONITORING PROGRAMS

A portion of the questionnaire was designed to obtain a general description of agency density control programs. Information was sought on details such as type of specifications employed and choice of test method and density standard.

Table 1 summarizes the individual agency responses to several of the general questions. Agencies were asked whether they use a method type or an end result type specification (or a combination of the two) and, if they use an end result specification, whether they test density by coring or by nuclear gauges. Because some agencies control density differently on full-depth pavements than they do on thin overlays, the table shows the procedures for full-depth pavements on the left and for thin overlays on the right. When an agency uses a different procedure for full-depth than for thin overlay construction, the maximum thickness for which the thin overlay specification is used is shown in the middle column. Finally, the number in parentheses after each State or province name is the number of nuclear gauges owned by the respective highway agency and used partially or entirely on asphalt concrete.

TABLE 1

DENSITY CONTROL PROCEDURE BY AGENCY

		Density Control Procedure*				
		Full-Depth Pavement		Thin Lift	Thin Overlay	
Agency	(Number of Gauges)	End Result Test	Method Specification	Cut Off (in.)	End Result Test	Method Specification
Alabama	(79)	N		2	C	
Alaska	(29)	N			N	
Arizona	(30)	N		1-1/2		M
Arkansas	(37)	C			C	
California	(115)		M			M
Colorado	(48)	N			N	
Connecticut	(13)	N			N	
Delaware	(17)	N				
Florida	(152)	N		1		M
Georgia	(84)	N			N	
Hawaii	(12)	N			N	
Idaho	(20)	N			N	
Illinois	(113)	N C			N C	
Indiana	(37)	N		2		M
Iowa	(0)	C			C	
Kansas	(22)	N			N	
Kentucky	(98)				N	
Louisiana	(0)	C			C	
Maine	(4)	C			C	
Maryland	(1)	C		1		M
Massachusetts	(11)	N C			N C	
Michigan	(69)	N			N	
Minnesota	(19)	N		1-1/2		M
Mississippi	(37)	N			N	
Missouri	(35)	N		2	C	
Montana	(66)	N			N	
Nebraska	(0)	C		1		M
Nevada	(16)	N		2		M
New Hampshire	(2)	C			C	
New Jersey	(0)	C			C	
New Mexico	(65)	N			N	
New York	(1)		M			M
North Carolina	(40)	N C			N C	
North Dakota	(18)	N			N	
Ohio	(20)				N	
Oklahoma	(29)	N C			N C	
Oregon	(34)	N C		1-1/2		M
Pennsylvania	(0)	C			C	
South Carolina	(13)		M			M
South Dakota	(13)	N		1-1/2		M

TABLE 1 (Cont'd)

Agency	(Number of Gauges)	Density Control Procedure*: Full-Depth Pavement: End Result Test	Full-Depth Pavement: Method Specification	Thin Lift Cut Off (in.)	Thin Overlay: End Result Test	Thin Overlay: Method Specification
Tennessee	(100)	N			N	
Texas	(106)		M			M
Utah	(55)	N			N	
Vermont	(4)	N C			N C	
Virginia	(169)	N			N	
Washington	(56)	N			N	
West Virginia	(80)	N		1-1/2		M
Wisconsin	(24)	N			N	
Wyoming	(22)	N			N	
Alberta	(32)	N C		2	C	
Manitoba	(22)	N C			N C	
Nova Scotia	(4)		M			M
Ontario	(0)		M			M
Saskatchewan	(12)	N		2	C	
TOTALS		39 17	6		27 17	16

*N=Nuclear, C=Cores, M=Method

SPECIFICATION TYPE

Highway agencies originally relied exclusively on method- or recipe-type specifications, in which they told the construction contractor what compaction equipment was acceptable and how it should be operated. More recently many agencies have shifted partially or wholly to end result specifications, in which acceptance of compaction is based on the results of density tests; equipment and rolling procedure choices are left to the contractor. Several agencies are dissatisfied with all of the procedures currently available for measuring the density of thin overlays. As a result, 10 of the 54 agency respondents use an end result specification for full-depth pavements and a method specification for thin overlays.

Examination of the agency specifications and survey responses shows that none of the agencies uses a pure end result specification for compaction. Although most of the agencies have come to rely on nuclear gauges or cores for acceptance tests, their specifications invariably include some equipment and compaction procedure requirements. Agencies listed in Table 1 as having end result specifications have specifications based primarily on nuclear gauge or core density acceptance tests. Agencies listed as having method type specifications have no acceptance test for density in their specifications.

TEST METHOD TYPE

Initially when the highway agencies began to monitor density, they relied on core density determinations. Four- or 6-inch diameter cores were removed from the compacted pavement and their densities were established in the laboratory. The laboratory procedures for gravimetric density measurements include ASTM (American Society for Testing and Materials) D 1188 and D 2726 (Ref. 1), AASHTO (American Association of State Highway and Transportation Officials) T 166 (Ref. 2), and local agency equivalents. The use of nuclear density gauges on asphalt concrete (AC) grew rapidly during the 1970's, as many agencies responded to the speed advantages of nuclear gauges over cores. The short test time for nuclear gauges allowed sampling frequencies to be increased. More importantly, it provided contractors with feedback while the AC pavement was still hot enough to allow further compaction.

Table 1 shows the current commitment of the agencies to nuclear gauges. Of the 48 State and provincial agencies which use an essentially end result specification for full-depth pavements, 31 depend primarily on nuclear gauges and another eight use a combination of nuclear and cores. Nine of the 48 rely on cores alone. A number of the agencies which use nuclear gauges primarily also use cores in certain situations, e.g., on small, remote projects (Alaska), on maintenance projects (Virginia), as a backup or alternate for nuclear gauges (Georgia, Kansas, Minnesota, and Saskatchewan), and on thin overlay projects (Alabama, Missouri, Alberta, and Saskatchewan). Also, as will be shown later, several agencies use cores to establish local correction factors to be applied to nuclear gauge readings.

THIN LIFT COMPACTION CONTROL

Table 1 also shows the problem the highway agencies have in controlling density on thin (1- to 2-inch thick) overlays. For these overlay thicknesses, the readings from nuclear gauges available at the time of the survey were sensitive to both the thin overlay and the underlying material. If the density of the underlying material is significantly different from that of the overlay, then the gauge density reading will not be the true density of the thin overlay. Coring is also not entirely satisfactory; it is slow and density determinations are very susceptible to errors because of the small volume of material involved. As a result, as Table 1 shows, 14 of the 48 end result specification agencies use a different specification for thin overlays than they do for thicker lifts. Ten of the 14 shift from an end result specification for full-depth pavements to a method specification for thin overlays, while the other four shift from nuclear gauge readings for full-depth pavements to cores for the overlays. The transition from one specification to the other occurs at layer thicknesses of 1 (3 agencies), 1-1/2 (5 agencies), or 2 (6 agencies) inches.

DENSITY STANDARDS

Agencies employing end result specifications are faced with another question, that being what target or density standard their field test results should be related to. The survey shows the agencies rely on either of two options, the use of a target established in the laboratory or the construction of a control strip. Laboratory-established standards include theoretical maximum specific gravity (ASTM D 2041 or AASHTO T 209), specific gravity of a Marshall specimen (ASTM D 1559 or AASHTO T 245), or the specific gravity of specimens established by other procedures. A typical specification would then require the average of five nuclear gauge tests in the field to exceed 92 percent of a theoretical maximum specific gravity or 95 percent of a Marshall specimen specific gravity.

The other option for nuclear gauge users is to use a control strip as the density standard. In a typical control strip approach, the contractor starts a project or a new mix design by placing a 500 foot strip on the field site. Nuclear gauge readings are taken at three locations on the strip after each pass of the compacting roller. When additional passes fail to increase density any further, the control strip is considered fully compacted, and its density average (established from readings at 10 locations on the strip) becomes the target for all subsequent lots on the project until the mixture is changed. A typical control strip specification would require the average of five nuclear gauge tests in the field to exceed 98 percent of the control strip density target. Some agencies require that the density attained in the control strip itself be some percentage of a laboratory density target.

The table below summarizes the responses on density standards from the agencies using end result specifications.

TABLE 2

DENSITY STANDARDS

	Laboratory Standard			
Agencies	Theoretical Maximum Specific Gravity	Marshall	Other	Control Strip
States	8	13	6	18
Provinces	0	3	0	0

Of the 18 states using the control strip approach, eight require the control strip density to be some percentage of a Marshall specimen or theoretical maximum specific gravity.

SAMPLING FREQUENCY

Sampling frequencies for compaction tests are specified in several different ways. In their survey responses, agencies stated frequencies in number of tests per lot, but, depending on the agency, lots were expressed in units of tons, square yards, lane-feet, or a day's or a fraction of a day's production. In order to allow sampling frequency comparison, each agency's frequency was converted to common units of one test per X lane-feet. (This required the following assumptions: (1) one day's production is 1,000 tons; (2) inplace density is 140 lbs/ft^3; and (3) paving is 1 lane, 12 ft wide and 2 in. thick.)

Table 3 shows the specified and the common unit sampling frequency for each agency; also the common unit sampling frequencies have been arranged in two columns, one for nuclear gauge users, the other for core users. The mean sampling frequency for the 37 agencies relying solely or primarily on nuclear gauges is 1 test per 1250 lane-ft, with test spacings ranging from 100 to 5200 lane-ft. The mean sampling frequency for the 10 core users is 1 test per 3283 lane-ft, with test spacings ranging from 750 to 7140 lane-ft.

TABLE 3

SAMPLING FREQUENCY
FOR END RESULT DENSITY TEST (FULL-DEPTH PAVEMENT) BY AGENCY

Agency	Nominal Sampling Frequency (Tests/Lot or Sublot)	Nuclear Gauge Sampling Frequency* (Tests/Lane-Ft)	Core Sampling Frequency* (Tests/Lane-Ft)
Alabama	1/0.5 Lane-Miles/Lift	1/2640	
Alaska	5/2500 Tons	1/3570	
Arizona	7/ 1/2 Day	1/510	
Arkansas	1/Day		1/7140
Colorado	1/500 Tons	1/3570	
Connecticut	5/Day	1/1428	
Delaware	5/Lane-Mile	1/1056	
Florida	5/5000 Lane-Ft	1/1000	
Georgia	5/Day	1/1428	
Hawaii	5/Day	1/1428	
Idaho	5/4000 Lane-Ft	1/800	
Illinois	5/2500 Ft	1/500	
Indiana	1/1000 Lane-Ft	1/1000	
Iowa	5/Day		1/1428
Kansas	3/Lane-Mile	1/1760	
Kentucky	1/1200 Yd^2	1/900	
Louisiana	5/1000 Tons		1/1428
Maine	1/500 Tons		1/3570
Maryland	3/Day		1/2380
Massachusetts	1/Lane-Mile		1/5280
Michigan	1/500 Ft	1/500	
Minnesota	5/Day	1/1428	
Mississippi	5/Day	1/1428	
Missouri	5/1,000 Ft	1/200	
Montana	5/2,000 Ft	1/400	
Nebraska	5/2,500 Tons		1/3570
Nevada	5/8,400 Yd^2	1/1260	
New Hampshire	2/Lane-Mile		1/2640
New Jersey	5/5,000 Yd^2		1/750
New Mexico	5/1500 Tons	1/2142	
North Carolina	5/1000 Ft	1/200	
North Dakota	1/1500 Yd^2	1/1125	
Ohio	15/5,000 Lane-Ft	1/333	
Oklahoma	1/Day		1/7140
Oregon	5/500 Tons	1/714	

TABLE 3 (Cont'd)

Agency	Nominal Sampling Frequency (Tests/Lot or Sublot)	Nuclear Gauge Sampling Frequency* (Tests/Lane-Ft)	Core Sampling Frequency* (Tests/Lane-Ft)
Pennsylvania	5/550 Tons		1/785
South Dakota	5/1000 Tons	1/1428	
Tennessee	5/10,000 Yd^2	1/1500	
Utah	1/1600 Yd^2	1/1200	
Vermont	1/1200 Ft^2	1/100	
Virginia	5/0.25 Miles	1/264	
Washington	5/400 Tons	1/571	
West Virginia	5/1000 Lane-Ft	1/200	
Wisconsin	3/750 Tons	1/1785	
Wyoming	2/Lift/2 Lane-Miles	1/5280	
Alberta	2/ 1/4 Day	1/893	
Manitoba	10/0.5 Miles	1/264	
Saskatchewan	1/ 1/5 Day	1/1428	
	AVERAGE	1/1250	1/3283

*Assuming AC production of 1000 average tons/day, placed in one 12 ft lane, 2 in thick, at 140 lbs/ft^3.

NUCLEAR DENSITY GAUGE USAGE

The second major portion of the survey questions focussed on how nuclear gauges are being used in monitoring AC compaction. Information was sought on details such as equipment, test procedures, problems, and techniques for use on thin overlays.

EQUIPMENT AND TYPE OF USE

Table 1 shows (in parentheses after each State or province name) the number of nuclear gauges used by each agency for density determinations on AC. (This number may not represent the total number of gauges owned, since some agencies may use cores or a method specification for AC, but use nuclear gauges on bases, subbases, and embankments.) Forty-two of the 54 responding agencies own more than 10 gauges, with six owning more than 100 each.

The agencies with nuclear gauge specifications reported that 60 to 100 percent of their gauge usage is for specification materials control, with most reporting 90 percent or more devoted to that purpose. Twenty-four of the 54 responding agencies are involved in research with or on nuclear gauges, 18 use the gauges to some extent for nonspecification checks on uniformity, and 16 use them for troubleshooting.

Only seven of the agencies reported having electronic or other operational problems with the gauges and most of those occurred with the pre-1980 models.

TEST PROCEDURE

Although ASTM D 2950 is a standard test procedure for "Density of Bituminous Concrete in Place by Nuclear Method," 32 of 38 respondents reported having their own agency standard procedure for nuclear density determinations. (AASHTO does not have a detailed test procedure in its books of standards, but T230 does allow nuclear gauge usage as one of the options for "Determining Degree of Pavement Compaction of Bituminous Aggregate Mixtures.") No attempt was made to compare the individual agency procedures with the ASTM standard for the present report.

Gauge users select their test configuration from three alternatives, backscatter, backscatter with air gap, and direct transmission. Backscatter is the most common mode for measurements on AC, but it is the most sensitive of the three to chemical composition and surface roughness effects. Backscatter with air gap is the method of choice of one of the three principal gauge manufacturers in the U.S., and, at least theoretically, eliminates chemical composition effects. Direct transmission is the most accurate procedure and the most widely used on soils and soil-aggregates, but it is rarely used on AC because it requires a hole to be punched or drilled in the pavement prior to the test. Table 4 summarizes current practice among the highway agencies (Some agencies use more than one operating mode; also, the direct transmission gauge numbers most likely reflect occasional or experimental use rather than standard use).

TABLE 4

NUCLEAR DENSITY GAUGE CONFIGURATION

Agencies	Backscatter	Backscatter with Air Gap	Direct Transmission
States	40	6	9
Provinces	4	0	0

GAUGE CALIBRATION

Calibrating nuclear gauges, i.e., establishing the relationship between gauge output count and sample density, is a critical step in getting good results. The highway agencies employ several different methods for calibration, as summarized in Table 5 below.

TABLE 5

CALIBRATION PROCEDURES

Agencies	Use manufacturers' curves only	Use own laboratory standards only*	Use manufacturers' curves adjusted by cores	Use own laboratory standards* adjusted by cores
States	5	17	7	16
Provinces	0	0	0	4

*to generate calibration curve or to adjust manufacturer's curves

Nuclear gauge manufacturers typically include calibration curves in the package when a gauge is purchased or returned after repairs (some of the latest model gauges have the calibration curve programmed internally). The manufacturer-supplied curves have been established by taking counts on a series of large natural and/or manufactured blocks and then statistically fitting a calibration curve through the data points. Table 5 shows only five States, typically those that own only a few gauges, rely on the manufacturer-supplied curves as their only calibration procedure. Agencies owning more gauges frequently acquire their own laboratory standards, typically of materials such as granite, limestone, and concrete; they use these either to generate their own calibration curves or to adjust manufacturer-supplied curves. One State, Connecticut, reports generating calibration curves from laboratory-fabricated AC blocks. Relying on calibration on laboratory standards is satisfactory if the agency has established that gauges are accurate on AC containing any aggregates used in the State.

The most widely used calibration procedure is to adjust the calibration curve on a project by project basis by applying a correction factor established from cores. Nuclear gauge readings and cores are both taken initially on a project, the average difference between the densities by the two methods is established, and that difference becomes an adjustment factor which is applied to all subsequent nuclear gauge readings. Considerable care must be taken when attempting to use cores to adjust calibration curves: (1) enough tests must be run by each method, cores and nuclear, to give statistically representative results; (2) cores with rough top and/or bottom surfaces must be paraffin-coated (otherwise the nuclear gauge will show lower density values than cores because of the inclusion of surface voids in the gauge's sensitive volume; (3) differences in the volume seen by each method must be recognized - the nuclear gauge is sensitive primarily to the top 2 inches of material and gives greatest weight to the material closest to the bottom of the gauge; and (4) coring and the subsequent gravimetric density determination must be done very carefully. Determining accurate gravimetric densities from cores of thin overlays is very difficult.

THIN LIFT COMPACTION CONTROL

Monitoring densities on thin overlays has been discussed in an earlier section of this report, but the use of nuclear gauges for that purpose deserves some further comment. As stated previously, 14 of the 48 agencies that use an end result specification on full-depth pavement construction change to a method type specification or change from nuclear gauges to cores on thin overlay construction. Twenty-seven agencies use nuclear gauges on both full-depth pavements and thin overlays, but they face a major problem on the latter: a reading from a standard backscatter gauge cannot be limited to only the overlay material. The displayed reading will be a weighted average of the densities of the overlay and the underlying material. Table 6 shows the percentage contributions that different thicknesses of typical AC material make to the displayed density value, for two commercially available gauges.

TABLE 6

DEPTH SENSITIVITY OF VARIOUS NUCLEAR GAUGE MODELS

Layer of Material (inches from top surface)	Percentage of Total Count from This Layer		
		CPN MC-1 Series Gauges (Ref.4)	
	Troxler 3400 Series Gauges (Ref.3)	Source in BS Position	Source in AC Position
0-1	52	51	70
0-1 1/2	70	68	89
0-2	83	81	94
0-3	96	94	98
0-4	98+	98+	99+

A nuclear gauge user seeking an accurate density determination on a 1-1/2 inch overlay must therefore compensate for the underlying material in some manner. The gauge manufacturers have provided some alternatives. In 1977, Troxler Electronics published an application note (Ref. 3) with a procedure for calculating the overlay density from the nuclear gauge reading and known or assumed values for the overlay thickness and the density of the underlying pavement. The accuracy of the overlay density determination depends on the accuracy of the latter two values. Seaman Nuclear uses a procedure similar to Troxler's but programs the calculation into the microprocessor in its gauges. The gauge user keys in the overlay thickness and underlying layer density values, and the gauge then automatically calculates and displays the overlay density value after each full-depth density determination. Campbell Pacific Nuclear (CPN) varies the source/detector/shielding geometry in its gauges to achieve two different depth sensitivities. CPN recommends that the deeper backscatter (BS in Table 6) position should be used for layers greater than 2 inches thick, that the shallower (AC) position should be used for layers 1.4 to 2.0 inches thick.

In 1982 the California Department of Transportation reported (Ref. 5) various attempts its researchers made to improve nuclear techniques for thin overlays. These included: (1) redesign of the source/detector/shielding geometry in a prototype gauge; (2) insertion of a magnesium or elastomeric layer between the gauge and the pavement to reduce the depth sensitivity; and (3) use of a conventional nuclear gauge with a mathematical model similar to the Troxler and Seaman procedures discussed previously. The researchers concluded all three methods showed some promise but needed additional development.

More recently, the same organization reported (Ref. 6) that attempts to develop a gauge or technique for reliable density determinations on layers down to 1.2 inches were unsuccessful. The researchers also concluded that existing backscatter gauges were effective for layers at least 1.8 inches thick.

Early in 1985 Troxler Electronics began marketing a "thin layer gauge." The company's brochures claim the new Model 4640 is suitable for density determinations on 1.0 to 2.5 inch thick layers. Seaman Nuclear also claims the "Accudepth" feature of its gauges allows accurate density determinations to be made on layers as thin as 3/4 inch. No highway agency evaluations of either manufacturer's gauges were found in the literature at the time the present report was being prepared.

The survey responses show the 27 agencies that currently use nuclear gauges on thin overlays treat the underlying material effect as follows: (a) 13 make a correction for the density of the underlying material using a procedure such as the manufacturer's application note referenced previously (Ref. 3); (b) 6 rely on control strips, thus assuming the overlay thickness and underlying material density both remain constant in the control strip and the sections being tested; and (c) 7 make no correction for the underlying material. If the last procedure is used, errors will be small where the density of the underlying material is close to that of the overlay or where the overlay is thick enough that the contribution of the underlying material to the gauge reading is small.

PROBLEMS

Table 7 below is a list of difficulties the agencies encountered in using nuclear density gauges on AC pavement. Ten agencies reported not having any problems.

TABLE 7

PROBLEMS IN USING NUCLEAR DENSITY GAUGES ON AC PAVEMENT

Problem	Number of Agencies Reporting
Poor agreement between cores and nuclear gauge readings	7
Effect of underlying material on gauge readings on thin overlays	5
Errors caused by surface roughness of coarse mixes	4
Gauge operator performance	3
Other	6

The most common problem is the lack of agreement between cores and nuclear gauge readings. Attempts to correlate the two methods by comparing measurements at exactly the same point in the field usually fail. Assuming both methods are performed properly and the nuclear gauge is calibrated, better correlation should be found by comparing the means and standard deviations of the two methods after tests at a number of locations within a given lot of material. Likely reasons for the poor correlations at specific sites include: the different volumes of material examined by each method; surface roughness effects and chemical composition effects on the nuclear gauge readings; surface roughness effects on the core density determination; inherent variability of both test methods; inadequate calibration of the nuclear gauges; and operator errors. Users should recognize <u>both</u> methods are subject to a variety of errors.

The effect of underlying material on gauge readings has been discussed previously in this report and has not yet been resolved satisfactorily. Errors caused by surface roughness are inherent in the backscatter method and become even more critical when gauges are redesigned to reduce their depth sensitivity for thin overlay measurements. Smoothing the texture by adding native fines to the surface can bring gauge densities more into agreement with core densities. Operator performance can be improved by initial and periodically repeated training and through other efforts to assure the quality of the testing program. Other problems cited at least once in the survey responses were: (1) the need for a method for establishing the dry density of emulsion mixes; (2) establishment of appropriate maximum density targets; (3) variability of readings from different gauges at the same location; (4) nonuniformity of AC mixtures; and (5) difficulties in getting maximum density in control strips.

TRAINING

The Nuclear Regulatory Commission (NRC) and the counterpart State agencies (in "Agreement States" the NRC delegates radioisotope licensing authority to an appropriate State agency) require all individual density gauge users to be trained in the safe handling of radioisotopes. Skillful use of nuclear gauges for accurate density determinations also requires training.

Table 8 summarizes the responses of the States and provinces to a brief series of questions about their training programs.

TABLE 8

TRAINING PROGRAMS

Number of agencies with training programs: 49

Training source:

In-house	32 agencies
Gauge manufacturers	5 agencies
Combined in-house and gauge manufacturer	12 agencies

Length of training (number of agencies reporting a particular training period):

	Days						
	0	1/2	1	1 1/2	2	3 or more	Until Proficient
Classroom	2	5	28	4	6	3	0
Field	9	11	9	2	8	5	4

CONTRACTOR USE OF NUCLEAR GAUGES

In recent years, most highway agencies have stressed compaction as one of the keys to increasing pavement life. Many have emphasized this concern by adding disincentive clauses to their specifications to reduce payments to contractors when compaction is not adequate. As a result, construction contractors are paying more attention to their process control; one approach has been to acquire nuclear density gauges for their own use. Table 9 below shows agency responses to the question of whether contractors use nuclear gauges to monitor compaction on their projects. (Current trends toward reduced highway agency staffing levels and increased contractor responsibility for quality assurance testing are likely to lead to more contractor ownership of nuclear gauges in the future.)

TABLE 9

CONTRACTOR USE OF NUCLEAR GAUGES

Contractor Use of Nuclear Gauges	Number of Agencies Responding
Frequent	2
Occasional	16
None	28

RESEARCH UNDERWAY

Although nuclear density gauges were heavily researched in the 1960's and early 1970's, the present survey shows only 13 of the 54 agencies responding had ongoing research involving the use of nuclear density gauges on AC. Table 10 below shows the research topic being investigated at the time of the survey (1983) and the agencies involved in studies on each topic.

TABLE 10

RESEARCH UNDERWAY

Subject	Agencies Involved
Correlation of nuclear gauge readings and core densities	AR, CT, GA
Use of gauges in roller pattern and roller effectiveness studies	ME, KY, NS
Development of end result specifications for compaction	CA, OH
Development of gauge procedures for use on thin overlays	CA, AB
Determination of asphalt content in place (using the moisture content measurement capability of nuclear gauges)	AZ
Effect of different aggregates on nuclear gauge performance	CT
Use of nuclear gauge to locate aggregate segregation sites	KS

RESEARCH NEEDS

Table 11 below shows the topics at least two responding agencies recommended for future research. The development of new nuclear gauge designs and test procedures for use on thin overlays is clearly the highest research priority currently.

TABLE 11

RESEARCH NEEDS

Research Subject	Number of Agencies Citing This Need
Use of nuclear gauges on thin overlays	14
Effect of surface voids on gauge readings	5
Correlation of nuclear gauge readings with core densities	2
Reproducibility between gauges	2
Determination of asphalt content using moisture content measurement capability of density gauges	2

Several subjects were only mentioned once, but may be of interest. These were: (1) development of roller-mounted density gauges; (2) adequacy of nuclear gauges for use in pay adjustment plans; (3) effect of different aggregates on gauge readings; (4) elimination of need to adjust nuclear gauge calibration from core densities; (5) sensitivity of nuclear gauge readings to heat (from use on hot AC mat); (6) method for dry density determinations on emulsion mixes: (7) changes in density values over period of days following construction (without traffic); and (8) development of 1 in. direct transmission measurement mode in a gauge for use on AC.

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APPENDIX

TRANSPORTATION RESEARCH BOARD
COMMITTEE ON INSTRUMENTATION PRINCIPLES AND APPLICATIONS

QUESTIONNAIRE ON STATE-OF-THE-ART IN NUCLEAR DENSITY GAUGE CONTROL OF ASPHALT CONCRETE COMPACTION

(If your agency does not use nuclear gauges for this purpose, please answer the questions in Sections D, E, H, I, & J.)

A. Equipment

1. List by manufacturer, model number, and approximate quantities, all nuclear testing or research equipment used for density determinations on asphalt concrete (AC):

MANUFACTURER	# MODEL	QUANTITY

2. List any such equipment which has performed unsatisfactorily on AC pavement since January 1973, and explain the problems: ________________

____

B. Equipment Use

1. Current status of equipment use (if used in more than one area list approximate percent of total use):

Laboratory Research	Field Research	Non-Specification Checks on Uniformity	Specification Materials Control	Troubleshooting (Problem Solutions)
☐	☐	☐	☐	☐

2. List published and unpublished reports, since 1973, by your organization on the use of these gauges on AC pavement. Include reports of applications as well as evaluations of the gauges themselves:

____

3. Describe any research or evaluation studies your agency currently has underway involving either nuclear density gauge use on AC or AC compaction control: ________________

4. Gauge calibration (check one or more):

Use Manufacturer's curves	Establish calibration from permanent stone, concrete, and other standards	Calibrate by comparison with conventional field tests (cores)	Other (Explain below)
☐	☐	☐	☐

5. Test Configuration (on AC only):

Backscatter	Backscatter with Air Gap	Direct Transmission
☐	☐	☐

C. Test Procedures

1. Does your agency have a test method for density gauge use on AC? ☐ Yes ☐ No. Do you use the ASTM procedure D2950? ☐ Yes ☐ No. If a method other than the ASTM procedure is used, please include a copy of the test method.

2. Testing requirements:

Indicate number of required individual density tests per lot (including lot size) and how tests are used to determine acceptance or rejection, e.g., average of five tests. ______________________________

____

D. Density Standards

1. How does your agency establish the maximum density for a project or lot?

Control Strip	Laboratory Compaction (Marshall or other)	Calculated	Other (Explain below)
☐	☐	☐	☐

Brief description of procedure ______________________________

____

2. If control strip technique is used, is the control strip density related to a laboratory maximum density? ☐ Yes ☐ No. How is the laboratory maximum established? ______________________________

____

3. Are you satisfied that the method used to establish the density standard is adequate? ☐ Yes ☐ No. If not, how should the density standard be established? ____________________

____

E. Specifications

1. Describe your compaction control specifications:

End-Result	Method or Procedural	Mixture of End-Result & Method
☐	☐	☐

F. Thin Lift Compaction Control

1. Do you use nuclear density gauges to monitor the density of thin lift or thin overlay (less than 2 inches) construction?

☐ Yes ☐ No

2. If yes, what special techniques are used?

☐ Corrections for the density of the underlying material.

☐ Spacers inserted between gauge and pavement.

☐ Modification to gauge.

☐ Other (describe) ____________________

____

3. How do you compensate for variations in the thickness of the overlay?

____

____

G. Training

1. Do you have a training program for personnel operating nuclear gauges?

☐ Yes ☐ No

2. If yes, whose training program do you use? ☐ Your Own ☐ Gauge Manufacturer's

Other (describe) ____________________

____

3. If yes, specify duration:

   Classroom ________________ Days

   Field ____________________ Days

4. Are operators certified? ☐ Yes ☐ No

H. Problems

Describe any difficulties your agency encountered in using nuclear density gauges on AC pavement and how you overcame them (if you did).

____

____

I. Research Needs

What specific problems involving the use of nuclear density gauges on AC pavement need research? _______________________________

J. Other Density Testing Methods

(Please answer these questions if ☐ your agency does not use nuclear gauges to monitor density of AC pavement or if ☐ your agency uses other methods in addition to nuclear).

1. Method for Controlling Compaction:

   ☐ Cores ☐ Other (describe) ____________________

   ____

2. What procedure do you use to control density on thin (less than 2 inches) lifts or overlays? _______________________________

   ____

3. Testing requirement: Indicate number of required individual density tests per lot (and lot size) and how the tests are used to determine acceptance or rejection, e.g., average of five tests. ____________________

   ____

4. Do contractors on your projects use nuclear gauges to monitor compaction?

   ☐ Yes, frequently ☐ Yes, occasionally ☐ No.

   If they do, please complete sections D & G.