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GUIDE FOR NUCLEAR METER ROOF MOISTURE SURVEYS

by
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P. O. Box 631, Vicksburg, Miss. 39180

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Final Report

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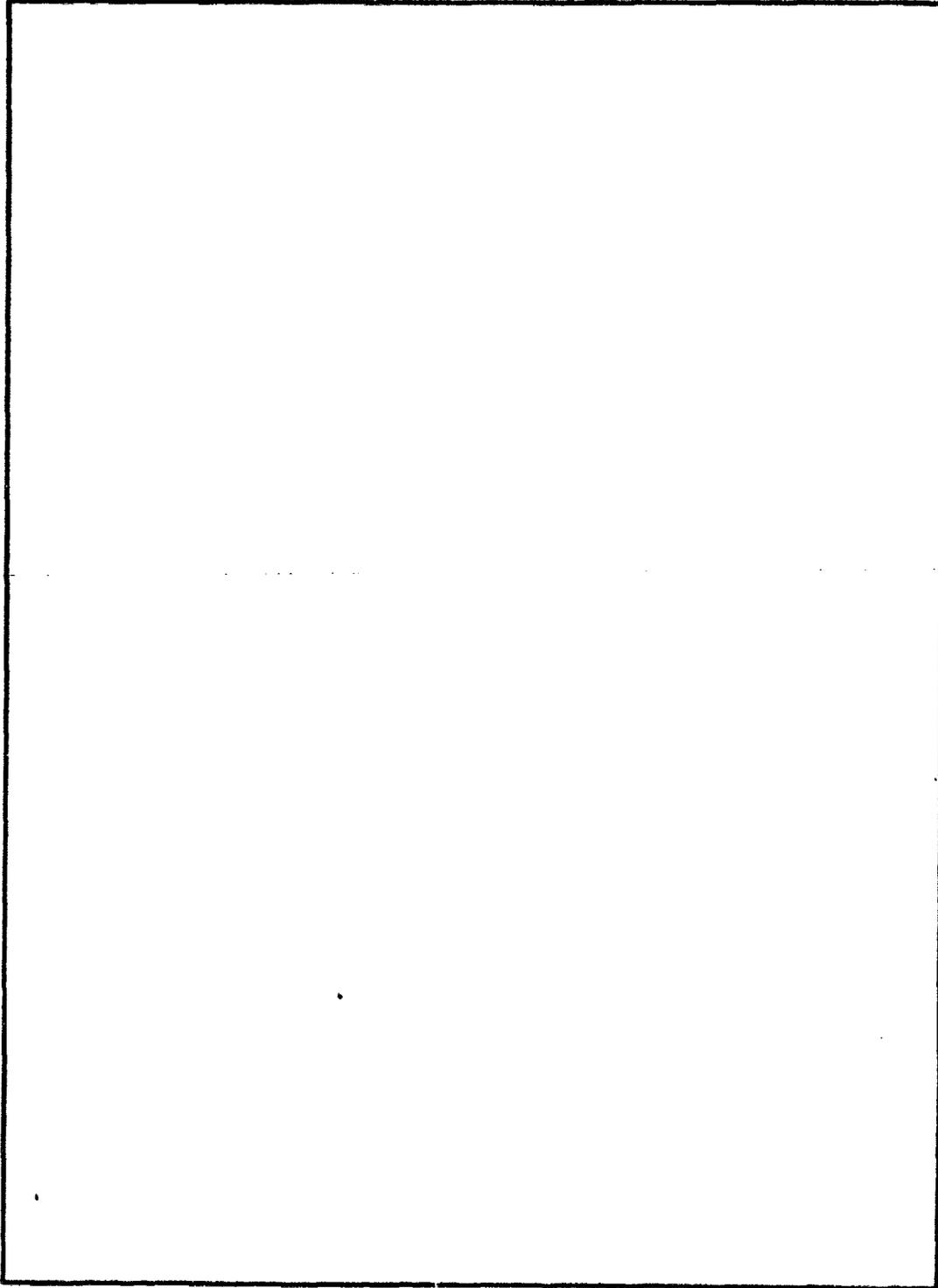
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PREFACE

The work reported herein was conducted from September 1976 to September 1978 by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The work was authorized under MIPR No. ACFM 76-4, dated 12 August 1976, from the U. S. Air Force Strategic Air Command, Offutt Air Force Base, Nebraska, to the WES, and under Work Unit C3, Moisture Detection in Roofs, Project 4A762730AT42, in conjunction with the U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

The study was conducted under the general supervision of Messrs. W. G. Shockley, Chief of the Mobility and Environmental Systems Laboratory, and B. O. Benn, Chief of the Environmental Systems Division, and under the direct supervision of Dr. L. E. Link, Jr., Chief of the Environmental Research Branch (ERB). Significant contributions were made to the content of the manual and development of the procedures presented by Messrs. C. A. Miller, A. Vazquez, C. Lebron-Rodriguez, and B. Helmuth of the ERB. Dr. Link and Mr. Miller prepared the manual.

The organization of WES laboratories underwent a structural change since this study was conducted. Organizations and individuals listed above as incremental to the Mobility and Environmental Systems Laboratory are now engaged under the Environmental Laboratory, of which Dr. John Harrison is Chief.

Commanders and Directors of WES during this work and preparation of this report were COL J. L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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TABLE 1

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
square feet	0.09290304	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

GUIDE FOR NUCLEAR METER ROOF MOISTURE SURVEYS

PART I: INTRODUCTION

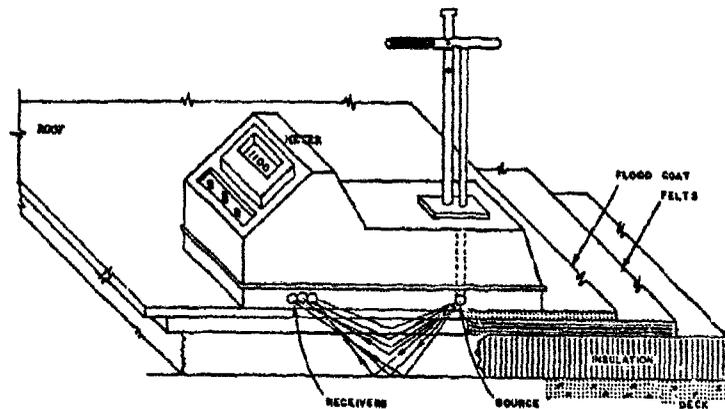
Background

1. Roof maintenance and repair is a multimillion dollar item in the yearly budgets of Armed Forces agencies. A majority of these costs are associated with flat, built-up roofs. A common phenomenon that creates a need for roof repair and replacement is the presence of leaks and associated entrapped moisture. If areas of entrapped moisture (i.e. moisture trapped under the roof membrane and commonly retained in the insulation) could be accurately delineated, repair operations could often be limited to those areas rather than to replace the entire roof, as is often done. A significant reduction in roof repair costs could be realized and many problems stopped before they became serious if entrapped moisture could be readily detected.

2. This report presents a rapid survey technique for delineating roof areas with entrapped moisture. The technique uses a nuclear moisture meter as the survey tool and is applicable to built-up roofs with insulation. The following paragraphs briefly describe the principles of operation for nuclear meters and outline their application to roof moisture surveys. Parts II, III, and IV present detailed step-by-step guidance for presurvey assembly of roof data, planning and conducting a roof survey, and analyzing nuclear meter data, respectively.

Basic Principles

3. Nuclear moisture meters emit fast neutrons and detect back-scattered slow neutrons. The process is illustrated in Figure 1a, and a nuclear meter is shown in operation in Figure 1b. The slow neutrons result from collisions between the fast neutrons and hydrogen atoms. Thus, the number of slow neutrons detected (or the rate of slow neutrons detected) is directly related to the number of hydrogen atoms present in



a. Illustration of how a nuclear moisture meter operates



b. Photograph of a nuclear moisture meter in operation

Figure 1. Nuclear moisture meters

the sample volume tested. Since water contains a large amount of hydrogen, the nuclear meter has the potential for detecting the relative amounts of water within materials tested.

4. To make a measurement, the nuclear meter is turned on, exposing a portion of the roof to fast neutrons. (The surface area affected is on the order of 10 sq ft.)* The detector counts the number of slow neutrons backscattered in a given time (or the rate of slow neutrons backscattered). A large number indicates lots of hydrogen (possibly water) while a low number represents less hydrogen (possibly no water). To determine if a nuclear meter reading represents a roof area with or without entrapped moisture, a threshold value separating wet and dry conditions must be established. Ideally, for a given set of roof conditions, higher nuclear meter readings may be directly tied to larger amounts of moisture in the roof. In practice, however, roof conditions vary markedly even on an individual roof and the nuclear meter survey technique can only reliably determine wet and dry conditions. It should not be used routinely to determine the degree of wetness.

Application

5. The nuclear meter procedure is an excellent and cost-effective means to survey portions or entire roofs on individual buildings and for surveying roofs on a number of buildings. As the number of buildings to be surveyed increases, the time involved to complete the survey increases proportionately. There is a point where the time frame may become excessive, although this constraint could be reduced by fielding multiple survey teams, the point being that other procedures are available that can be used to cover large areas (i.e. many buildings). The alternatives are hand-held or airborne thermal infrared (IR) imaging devices. The hand-held IR devices are used on the roof at night by a team

* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 3.

that simply walks around examining the roof for warm areas that may indicate entrapped moisture. The hand-held IR devices are quite expensive and sophisticated but offer a rapid survey capability. Information on use of these devices is available in the following publication:

"Detecting Wet Roof Insulation With a Hand-Held Infrared Camera," by Charles Korhonen and Wayne Toblasson, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, August 1978.

6. Airborne thermal IR imaging techniques provide a means to rapidly survey the buildings of an entire installation. Such surveys must be accomplished at night using military reconnaissance or commercial aircraft. The resulting imagery is a photolike presentation of the roof tops (and other features on the installation) on which warm areas indicating entrapped moisture can be identified. Details on planning and conducting airborne roof moisture surveys are given in the following publication: "Guide for Airborne Infrared Roof Moisture Surveys," by L. E. Link, Instructional Report M-78-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., January 1978. The airborne survey procedure is best used as a reconnaissance technique to identify potential problem areas which can be examined in more detail by on-the-roof techniques such as the hand-held IR or the nuclear meter devices.

7. Use of the nuclear meter is a simple procedure requiring only the nuclear meter, a calibration block, and a balance to weigh roof samples. The work can be carried out by two people who need only a small amount of training with the instrument. Data analysis can be a simple manual process or performed with a desk calculator statistical procedure or standard statistical computer programs. Both techniques for data analysis are discussed subsequently in this report. Personnel using the nuclear meter should have a basic understanding of radiological safety which can be obtained in a correspondence course given by the Army Chemical School, Aberdeen Proving Ground, Maryland,* or through introductory

* Radiological Safety, Course No. FK-F3, U. S. Army Ordnance and Chemical Center and School, ATTN: ATSL-CLT-P (Mr. Bradley), Aberdeen, Md. 21005, Telephone (301) 271-2011.

courses given by many of the nuclear meter manufacturers. The radiation safety officer at each installation can provide guidance concerning requirements for this training. This document presents the recommended step-by-step procedure for conducting a nuclear meter roof moisture survey. The remaining portion of this manual is divided into assembly of roof data, planning the roof survey, conducting the roof survey, and data analysis. The discussion is based on the use of a Troxler 2401 nuclear meter, although similar types of meters can be used without changing the procedure of the roof survey significantly. Table 1 lists some nuclear meter manufacturers and sources of nuclear meter surveys.

PART II: PRESURVEY ASSEMBLY OF ROOF DATA

8. Basic information on the character of the roofs to be surveyed is needed to aid in planning the nuclear meter survey and data analysis.

The information needed is as follows:

- a. Scale drawings of roofs. These drawings will be used to both record nuclear meter readings at the locations they were taken and to delineate the areas of wet insulation as determined by the moisture survey.
- b. Physical characteristics of each roof. The physical make-up of each roof to be surveyed should include type of roof deck, thickness and type of insulation, number of felt plys, and type and thickness of flood coat. These data can be used for consolidating roof areas during the data analysis.
- c. Location and character of physical features of the roofs. Physical features such as air vents, evaporators, chimneys, drains, and expansion joints are typically conducive to water infiltration into the insulation. These features should be overlaid on the scale drawing of the roof area with the intent to take additional meter readings around these penetrations.
- d. History of roof maintenance. It is valuable to know where patches have been made, when reroofing has been done, and which roofs are nearing their design ages. Patches may cause higher nuclear meter readings if an additional amount of bitumen is present compared to the rest of the roof.

PART III: PLAN AND CONDUCT OF THE ROOF SURVEY

Planning Roof Surveys

9. The nuclear meter cannot be used successfully on built-up roofs that have no insulation. Thus, the first step in the planning process is to eliminate all such buildings from further consideration.

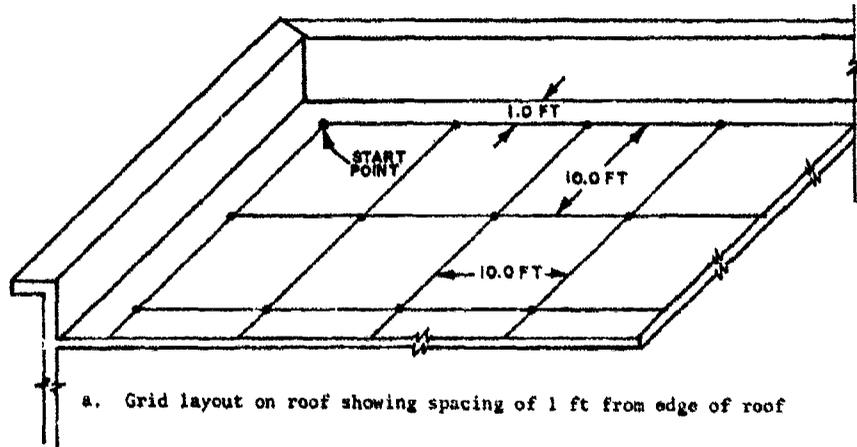
10. The nuclear meter is most effective when the roof or roof area has uniform conditions or characteristics. Thus, one of the basic purposes in planning the roof survey is to identify roofs and roof areas having similar characteristics (deck, insulation type and thickness, number of felt plys, etc.). For example, if a building has a new and old wing and the roofs on the two wings have different deck materials and different thicknesses of insulation, the nuclear meter data obtained on each wing should be analyzed separately.

11. In the planning step, the data on roof characteristics should be examined to identify the following:

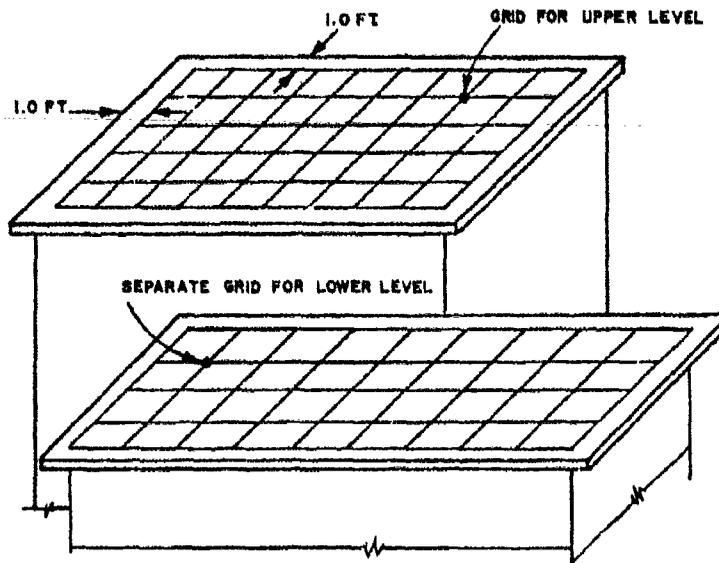
- a. Roofs having uniform conditions.
- b. Areas of roofs that differ in character such as wings, different elevation levels, or a portion that has been repaired or reroofed in the past.
- c. Buildings with similar roof conditions such as barracks or warehouses.

The results of the planning process should include a list of the above information with appropriate boundaries for item b marked on the scale drawings of the roofs.

12. When the roofs to be surveyed have been identified, it is necessary to mark a grid pattern on the scale drawing of each roof. The grid size recommended is 10 by 10 ft unless finer definition is desired. Figure 2 illustrates the grid layout on single and multilevel roofs. A corner of the building (roof) should be selected as a starting point and all the grid coordinates should be referenced to it. On buildings having multilevel roofs, it may be necessary to establish a new starting point on each level. Grid intersections should be drawn on the roof plan as accurately as possible since they will be used as a reference



a. Grid layout on roof showing spacing of 1 ft from edge of roof



b. Grid layout on multilevel roofs

Figure 2. Grid layouts on roofs

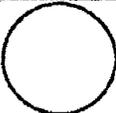
for recording the locations of nuclear meter readings during the nuclear meter survey. The grid should be set up so that the locations of nuclear meter readings along the outer edges of buildings will be at least 1 ft from the edge.

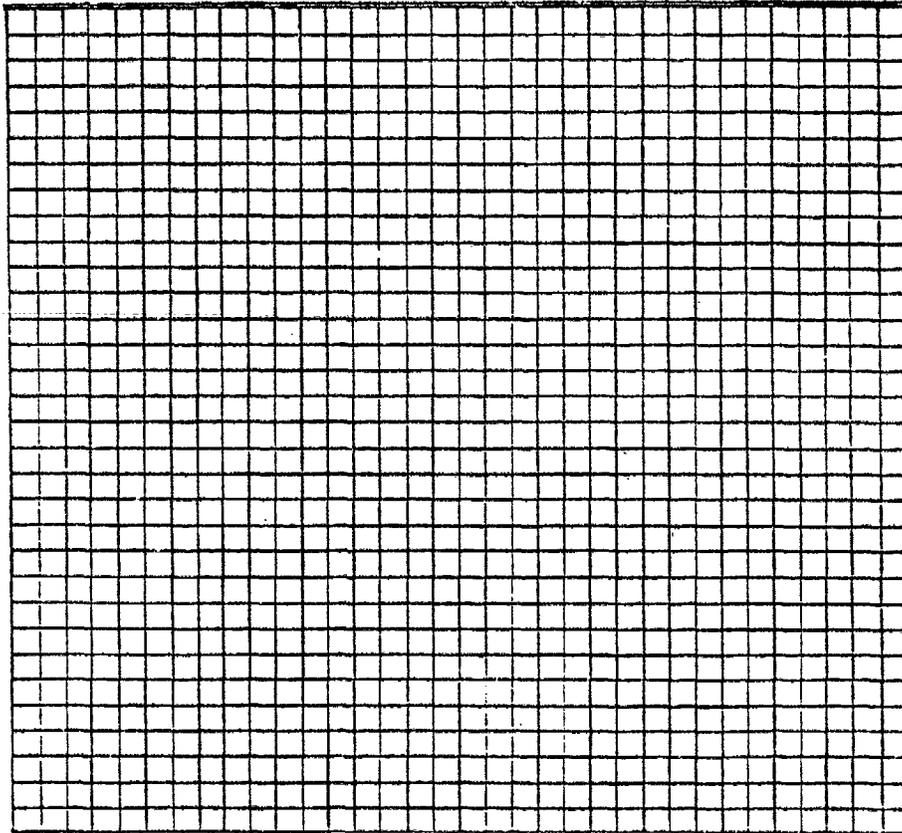
13. Nuclear meter surveys must be made when the roofs are free of standing water and snow. Thus, it is best to schedule the surveys during the driest part of the year to prevent lost time during periods of rain or snow.

Conducting Roof Surveys

14. The nuclear meter survey should be conducted in the following manner for each roof or roof area having uniform characteristics:

- a. Lay out grid on roof. The grid should match as closely as possible that previously placed on the roof plan drawing. The grid size is recommended to be no larger than 10 by 10 ft (see Figure 2). Figure 3 gives a convenient form for drawing roof plans and recording observed roof conditions.
- b. Calibrate nuclear meter. Record nuclear meter type, serial number, day, and time of day along with calibration reading. Calibration procedures are included in the operating instructions for individual nuclear meters.
- c. Systematically obtain nuclear meter readings at each grid intersection. Record readings by grid coordinates in a notebook or directly on a plan drawing of roof that has the grid intersections shown on it. The nuclear meter readings should represent 30-sec counts for standard counting-type meters and at least a 10-sec reading for rate-count meters. Figure 4 illustrates the nuclear meter readings recorded on a plan drawing and notebook for a portion of a roof.
- d. When readings have been obtained over an entire roof area, obtain another calibration meter reading to note if any drift in the meter calibration has occurred. Normally, no drift will occur. If it does, the readings should be adjusted. The adjustment can be a single linear function of time. For example, assume a morning calibration reading was measured to be 500 and in the evening of the same day the reading was 532 (over an 8-hr period). The hourly correction during the day would be $532-500/8$ or 4 m units per hour. Thus, readings taken approximately

LOCATION: _____ BUILDING: _____ DATE: _____ 19____
(Day) (Mo.) (Yr.)
MAGNETIC NORTH:  SURVEYED BY: _____
(name)



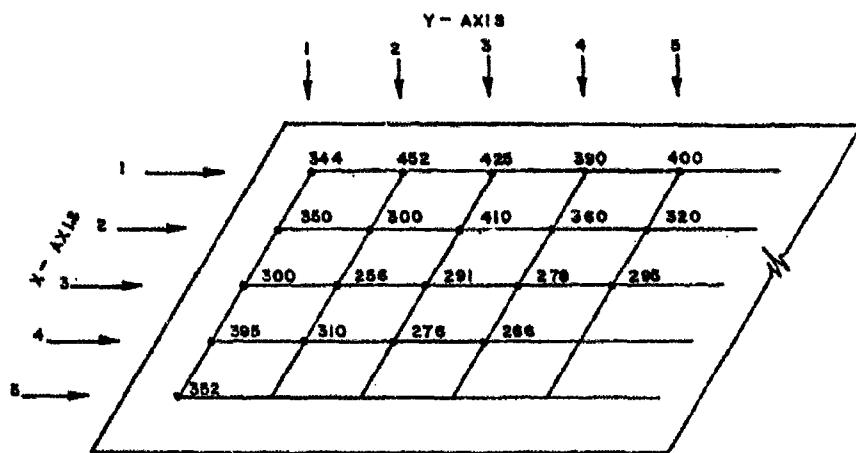
REMARKS:

Figure 3. Sample roof survey work form (Continued)

<p><u>ROOF SURFACE</u></p> <input type="checkbox"/> gravel <input type="checkbox"/> bare felt/s <input type="checkbox"/> aluminized <input type="checkbox"/> emulsion <input type="checkbox"/> other _____	<p><u>MEMBRANE</u></p> <input type="checkbox"/> alligatoring <input type="checkbox"/> blisters <input type="checkbox"/> exposed felts <input type="checkbox"/> cracks <input type="checkbox"/> mem. creep <input type="checkbox"/> fishmouths <input type="checkbox"/> bucklas <input type="checkbox"/> splits <input type="checkbox"/> debris <input type="checkbox"/> dry/brittle <input type="checkbox"/> sample dslaminates <input type="checkbox"/> good <input type="checkbox"/> other _____	<p><u>TYPE OF INSULATION</u></p> <input type="checkbox"/> none <input type="checkbox"/> glass fiber <input type="checkbox"/> perlite <input type="checkbox"/> board <input type="checkbox"/> loose <input type="checkbox"/> gypsum <input type="checkbox"/> lc-wt-concrete <input type="checkbox"/> organic fiber <input type="checkbox"/> other _____
<p><u>DRAINAGE</u></p> <input type="checkbox"/> sloped <input type="checkbox"/> internal <input type="checkbox"/> scuppers <input type="checkbox"/> gutters (outside <input type="checkbox"/> /inside <input type="checkbox"/>) <input type="checkbox"/> eaves <input type="checkbox"/> ponded water <input type="checkbox"/> clogged-outlets <input type="checkbox"/> missing/misplaced parts <input type="checkbox"/> other _____	<p><u>TYPE OF DECKING</u></p> <input type="checkbox"/> concrete <input type="checkbox"/> metal deck <input type="checkbox"/> wood frame <input type="checkbox"/> other _____	
<p><u>FLASHING CONDITION</u></p> <input type="checkbox"/> poor <input type="checkbox"/> fair <input type="checkbox"/> good <input type="checkbox"/> excellent	<p><u>ROOF HISTORY (see comments)</u></p> <input type="checkbox"/> leaks when, where <input type="checkbox"/> age of roofs <input type="checkbox"/> repairs <input type="checkbox"/> maintenance <input type="checkbox"/> leaks every rain <input type="checkbox"/> leaks melting snow	
<p><u>WATERPROOFING AGENT</u></p> <input type="checkbox"/> asphalt <input type="checkbox"/> coal tar pitch		

COMMENTS:

Figure 3. (Concluded)



a. Plan drawings of the roof

NUCLEAR METER SURVEY		
METER :		
TYPE :		
CALIBRATION :	TIME :	
ROOF :	DATE :	
NUCLEAR METER	COORDINATES	
<u>READING</u>	<u>X</u>	<u>Y</u>
344	1	1
452	1	2
425	1	3
⋮	⋮	⋮
⋮	⋮	⋮

b. Notebook

Figure 4. Illustration of methods to record nuclear meter readings

4 hr after the first calibration measurement should have 4 by 4 or 16 units subtracted from their value to normalize them back to values comparable to the readings taken at the start of the survey. The specific way that calibration reading changes are utilized is up to the individual user.

- e. Examine nuclear meter readings (this is much easier if they are recorded on the scale drawing of the roof) to determine the approximate range in the nuclear meter readings obtained.

- f. Obtain a core sample at the roof location where the largest nuclear meter reading was obtained. Do this for both the center and edge of the roof (i.e. treat the readings taken around the edges of the roof independent of those taken in the center roof areas). If the insulation in either of the cores is wet (i.e. obviously wet or damp to the touch), obtain cores at locations where nuclear meter readings were approximately three fourths of the highest readings. For example, if wet insulation is found where the nuclear meter reading was 400, take a second core in a location where the nuclear meter reading was approximately 300. If the second core has wet insulation, repeat the process (take a third core where the reading was 225). If the second core was dry, a third core sample should be taken for a nuclear meter reading midway between the values of the nuclear meter readings at the locations where the first and second cores were made (e.g. 350). The nuclear meter readings and grid coordinates for each core sample should be recorded and then the sample should be weighed and sealed in plastic bags for later processing.

- g. Dry the roof samples in an oven for 48 hr at 150°F and weigh again. Determine the percent moisture (by weight) using the relation

$$\frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} = 100 \text{ percent}$$

Samples having moisture content values greater than 15 percent are considered to have entrapped moisture.

- h. If only dry cores are obtained, consider that roof or roof area to be completely dry (i.e. no entrapped moisture is present): do not conduct the data analysis procedure on those data. It is recommended that at least two core samples be taken at the highest meter readings to ensure that no moisture exists.

15. Since nuclear meter readings are taken at regular intervals (at grid intersections) along a specified grid system, it is possible that small areas of a deteriorated roof may go undetected. This problem can be rectified to some extent by using personnel with experience in roof maintenance to point out locations where possible wet conditions exist, such as around penetrations in the roof membrane, which would otherwise be overlooked. Additional nuclear meter readings should be made in these areas. A complete log should be kept during the roof survey, documenting any irregularities in the roof system that could be seen visually on the surface, with a description of each core sample taken.

PART IV: DATA ANALYSIS

16. The primary purpose of the data analysis procedure is to establish a threshold nuclear meter reading(s) that can be used to delineate roof areas with entrapped moisture. Properly defined, nuclear meter readings above the threshold represent wet conditions and readings below the threshold represent dry conditions. By mapping or drawing lines around all roof areas (on the roof plan) having nuclear meter readings above established threshold values, the areas with a high probability of having entrapped moisture are delineated.

17. The following paragraphs explain two processes (manual and statistical) by which the threshold nuclear meter reading can be calculated from the data. The manual analysis employs the use of a larger number of core samples but can be done in the field in a relatively short period of time. The statistical analysis usually requires the use of a computer system; however, the computations can be accomplished with a desk calculator. The advantage of this method is that small variations in roof structure are accounted for in the statistical averaging of the data. An example is presented in the following paragraphs of the use of both analysis techniques to compute the wet-dry threshold value.

Manual Data Analysis Technique

18. The main advantage of the manual analysis technique is that the threshold nuclear meter reading can be determined rather quickly and is determined in the field. This analysis utilizes the results of the core samples and the corresponding nuclear meter readings as described in paragraph 14f and 14g. If a field assessment of insulation wetness is desired, the determination must be made by physically touching the insulation with the fingers to detect if moisture is present. Obviously, this method is not completely foolproof, and it is recommended that the standard oven drying method be used if possible.

19. In most cases, the threshold reading can be determined for the center section of the roof by taking no more than four core samples.

Usually, four core samples will provide a threshold reading having an accuracy of ± 10 percent. Each additional core sample will double the accuracy of the previous number of cores.

20. As explained in paragraph 14, a core sample is taken at the highest meter reading, at three fourths the highest reading, at three fourths the previous reading, etc., until a dry sample is found. If the difference in the lowest wet reading and the highest dry reading is greater than 50, another core sample should be taken at a meter reading approximately midway between these values. According to the status (i.e. wet or dry) of the last cover sample taken, the threshold should be determined to be the meter reading midway between the lowest wet reading and the highest dry reading. This threshold is assumed to be the nuclear meter reading associated with an insulation moisture content of 15 percent.

21. The procedure may be repeated for the edge and joint areas or the thresholds for these areas can be computed using the regression equations presented in paragraph 22. In either case, the threshold is then used to delineate areas of wet and dry insulation. For the sake of conservatism (one would not want to delineate a wet area as dry), it is recommended that nuclear meter readings equal to the threshold reading be delineated as wet. If the threshold determination is made without the use of oven-dried samples (paragraph 14g), it is recommended that the threshold be chosen to be slightly higher than the highest dry reading.

Statistical Data Analysis Technique

22. The statistical data analysis, as outlined below, should be applied to the nuclear meter readings obtained from each individual roof or roof area having uniform roof characteristics. The basic steps are as follows:

- a. Separate the nuclear meter readings into those obtained along roof edges, those obtained along expansion joints and penetrations, and those obtained in central roof areas. Edge-and-joint readings may be combined if the

characteristics (vertical material section) of the edges and joints are similar.

- b. Prepare a histogram of the center area readings. The histogram is simply a graph showing the number of times the nuclear meter readings fell into specific value categories. Figures 5 and 6 are examples of histograms. Figure 5 shows a histogram that is bimodal or that has two peaks. Ideally, the nuclear meter readings to the left (lower values) of the depression separating the peaks represent dry roof areas and the nuclear meter readings to the right (higher values) of the depression represent roof areas having entrapped moisture. Areas where nuclear meter readings greater than the threshold were obtained are considered to have entrapped moisture. A similar analysis can be made for edge-and-joint nuclear meter readings, if desired. A simpler process has been established to determine threshold values for center roof areas. This process will be discussed in subsequent steps.
- c. If the histogram of nuclear meter readings is similar to that shown in Figure 6, the nuclear meter data are said to have a skewed distribution, and the wet-dry threshold is not as easy to determine. When this situation occurs, the threshold is determined by using simple statistics and the core sample data. Basically, the nuclear meter readings (for central roof areas) are divided into two groups: those having a value equal to or greater than the lowest nuclear meter reading corresponding to a wet (>15 percent) core sample; and those having a value equal to or less than the highest nuclear meter reading corresponding to a dry core sample. A normal distribution curve is drawn for each group and is plotted as shown in Figure 7. The procedure for calculating the normal distribution curve is based on the mean and standard deviation of each group of readings and can be found in any basic statistics book. Most computer centers have library programs to make such calculations, but they can also be accomplished on a small desk calculator. The threshold value can be chosen as the value at the intersection of the two curves (now having an appearance similar to the histogram in Figure 5).
- d. To establish nuclear meter threshold values for roof edges and expansion joints, use the equations

$$\text{Edge threshold} = 55 + 0.92 [\text{center threshold}]$$

and

$$\text{Joint threshold} = 22 + 1.09 [\text{center threshold}]$$

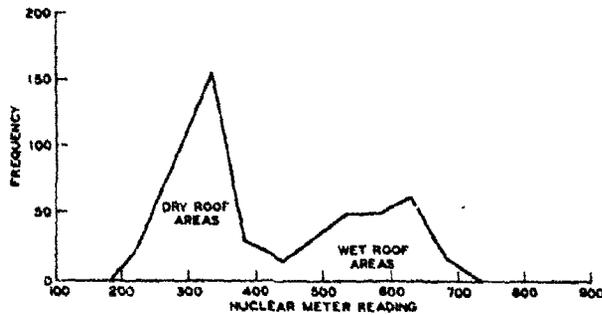


Figure 5. Frequency histogram of nuclear meter readings showing bimodal character; buildings 525, 526, and 527, Offutt Air Force Base, Nebraska

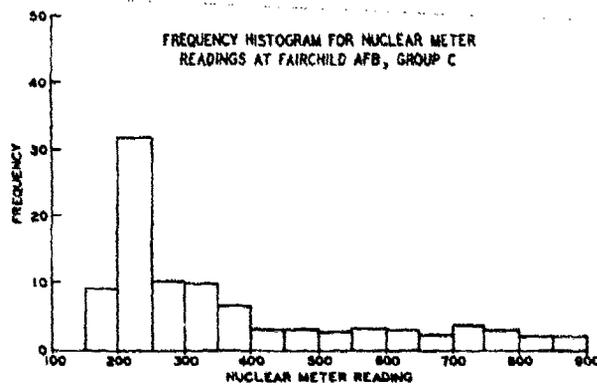


Figure 6. Frequency distribution of nuclear meter readings lacking bimodal character (skewed)

NOTE: The plots in Figures 5 and 6 are plotted differently, but are both histograms. They illustrate two common methods of plotting histograms.

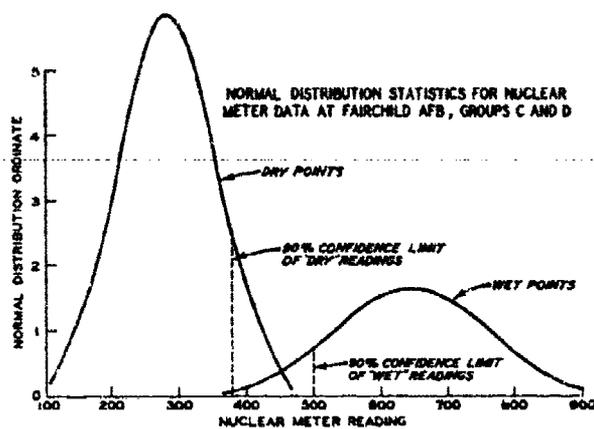


Figure 7. Computed normal distribution curves for wet and dry values as determined by core samples and a statistical analysis procedure

If edge-and-joint conditions are similar, only the first equation need be applied for both edges and joint.

- e. Using the established threshold values, map out the roof areas with a high probability of having entrapped moisture. All roof areas having nuclear meter readings greater in value than the appropriate threshold value are considered to have entrapped moisture.

23. If several roofs occur that have identical characteristics, the data for those roofs can be combined and analyzed together. The same threshold values would be applied to all of the roofs.

Example Application of Analysis Procedures

Data

24. The data used in this example application of nuclear meter data analysis procedures were obtained on the library of the U. S. Army Military Academy, West Point, N.Y., during April 1976. A Troxler Model 2401 moisture-density meter containing a cesium 137, americium 241, beryllium radioactive source was used to obtain the measurements. The data were obtained on a 10- by 10-ft grid and using a 30-sec count period.

25. Figure 8 illustrates the outline of the portion of the library roof used in this example with the actual nuclear meter readings shown for each grid intersection. The data shown in the figure were used to compute threshold values by both the manual and statistical analysis procedures.

Application of manual procedure

26. The nonedge nuclear meter readings were examined to select positions of core samples. The first core sample was taken at the position of a nuclear meter reading of 336. This sample had a measured moisture content of 147 percent. A second core was made for a nuclear meter reading of 241 (approximately 75 percent of the first). This sample proved dry (0.5-percent moisture content). A value midway between the two was then investigated (279) which turned out to be wet (60-percent moisture content). The threshold was selected to be midway

X

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	288 904	194 902	191 912	182 922	189 912	185 932	188 932	184 922	171 942	214 942	209 922	228 942	241 942	267 912	310 012	201 922	474 922
2	316	186	186	178	224	296	199	208	181	187	188	208	605	423	493	457	927
3	265	193	174	184	285	248	188	180	175	188	272	88	915	915	915	915	915
4	270	184	184	334	204	192	186	188	207	188	288	915	915	915	915	915	915
5	224	182	185	184	238	181	185	178	172	177	278	944	944	944	944	944	944
6	311	188	187	388	179	279	187	178	188	222	382	684	684	684	684	684	684
7	502	482	418	515	484	838	838	808	491	878	852	852	852	852	852	852	852

Y

Figure 8. Plan drawings of Level A of library building roof, West Point Military Academy, New York, showing nuclear meter readings

between 279 and 241 or 260. Thus, all values above 260 (for center measurements) were considered to be wet. The regression equation given in paragraph 22d was used to establish a threshold for edge readings which was computed to be 294.

27. Applying the center (260) and edge (294) thresholds to the data shown in Figure 8 results in the definition of wet areas as shown in Figure 9.

Application of statistical procedure

28. The statistical procedure was applied as outlined in paragraph 22. The following paragraphs show the individual steps in the procedure as applied to the West Point Library data.

29. The central roof area nuclear meter readings were separated from the others and a histogram was prepared. The histogram is shown in Figure 10. Since no bimodal character is evident, core sample data were analyzed to help establish a threshold value. The core sample data obtained were as follows:

<u>Nuclear Meter Reading</u>	<u>Percent Moisture Content</u>
336	147.0
236	0.6
279	60.0
175	0.3

On the basis of these values, all values below 236 (the highest dry readings) and all values above 279 (the lowest wet reading) were lumped and analyzed statistically. Normal frequency distributions were computed for each of the above sets of numbers along with corresponding 90-percent confidence limits. These are shown in Figure 11.

30. The threshold value based on the curves shown in Figure 11 was selected to be 265. This represents the approximate intersection of the two normal frequency distribution curves. Using the regression equation in paragraph 22d, the edge threshold value was computed to be 299. Applying these threshold values to the data in Figure 8 results in the definition of areas shown in Figure 12 as having entrapped moisture.

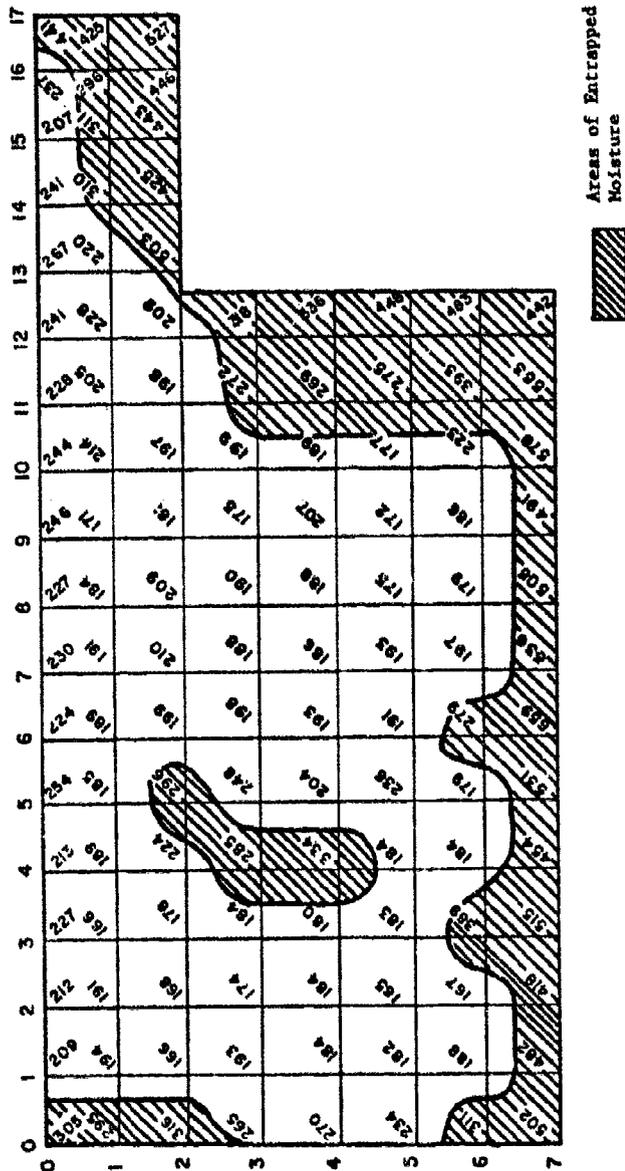


Figure 9. Results of application of manually derived threshold values to nuclear meter data for Level A of library, West Point Military Academy

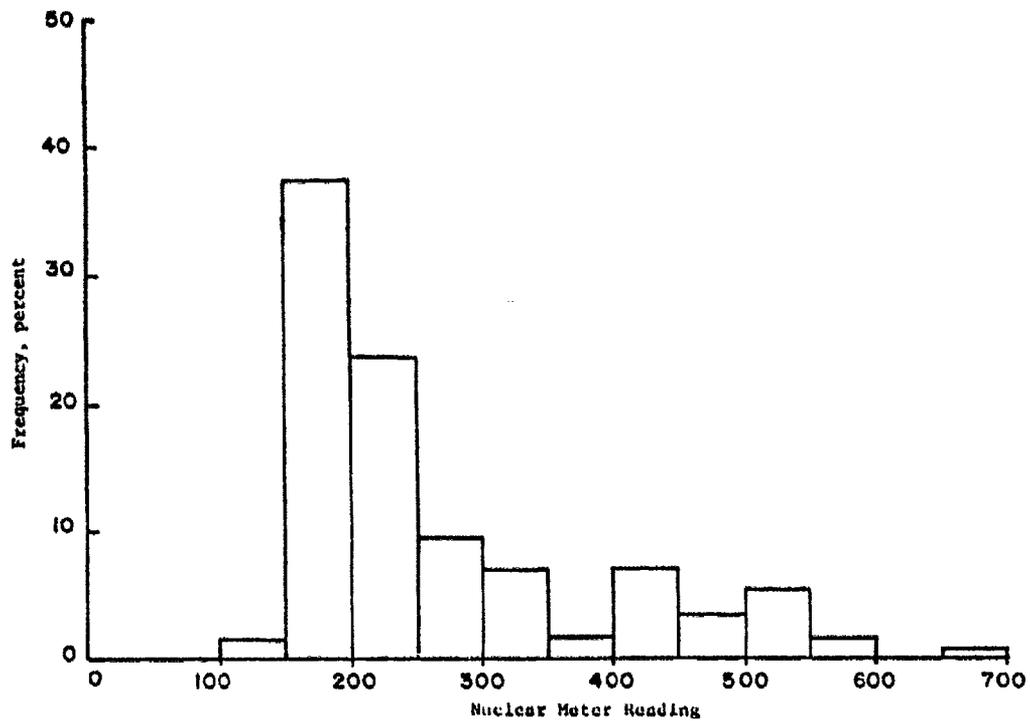


Figure 10. Frequency histogram for nuclear meter data (center) of Level A of library, West Point Military Academy

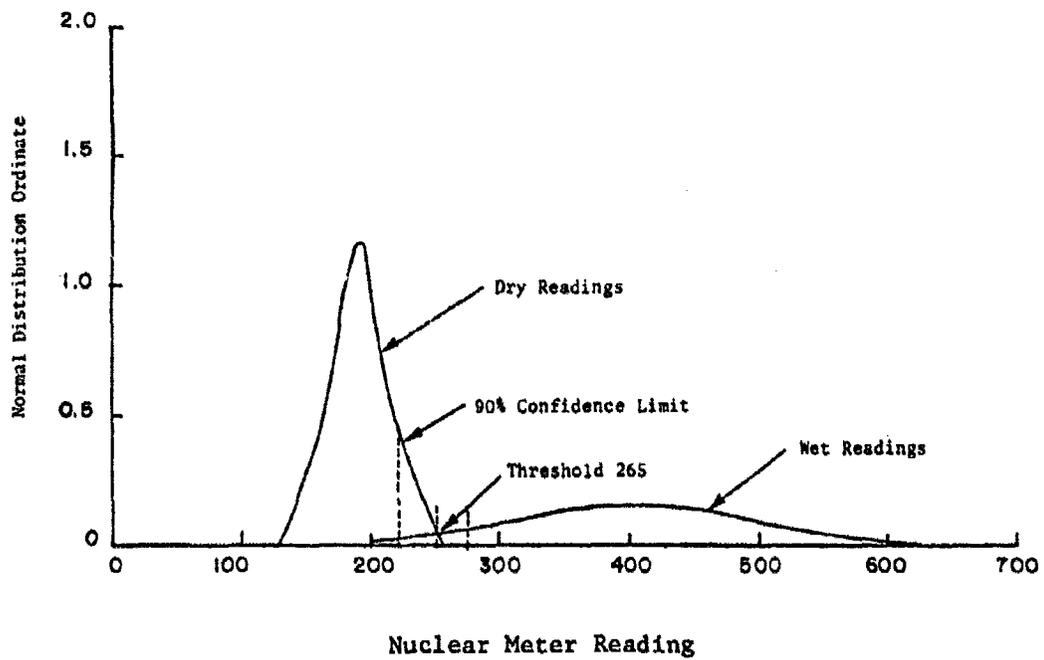


Figure 11. Computer normal frequency distributions for wet and dry nuclear meter readings, Level A of library, West Point Military Academy

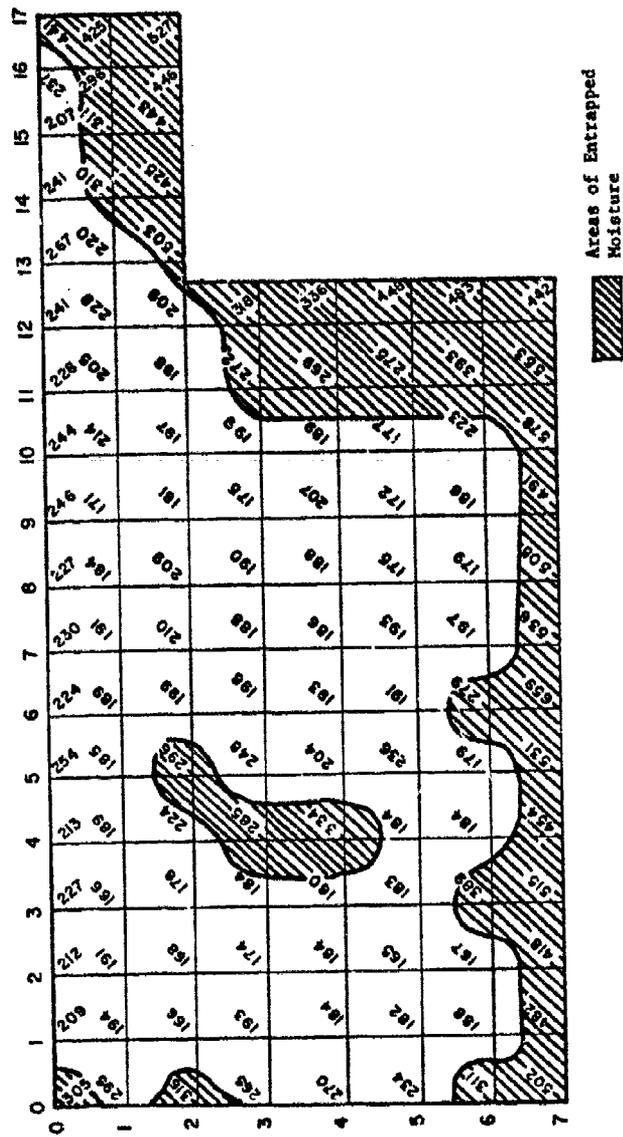


Figure 12. Results of application of statistically derived threshold values to nuclear meter data for Level A of library, West Point Military Academy

31. Careful comparison of Figures 9 and 12 reveals that only the area in the neighborhood of the nuclear meter reading 295 ($X = 0$, $Y = 1$) is classed differently because of differences in the threshold values determined by the manual and statistical methods.

Recording Information

32. A permanent record should be maintained for each roof (especially those determined to have entrapped moisture). Figure 13 shows a possible format. The figure is a scale drawing showing the areas suspected of having entrapped moisture. Added to this figure would be a narrative providing the information obtained during the assemblage of the data (Part II) plus any pertinent remarks from observations made while the roof survey was conducted. Such a record would help in future nuclear meter surveys of the same roof or similar roofs, providing a record of conditions when the survey was obtained and providing a mechanism by which to monitor expansion of entrapped moisture or effectiveness of repairs.

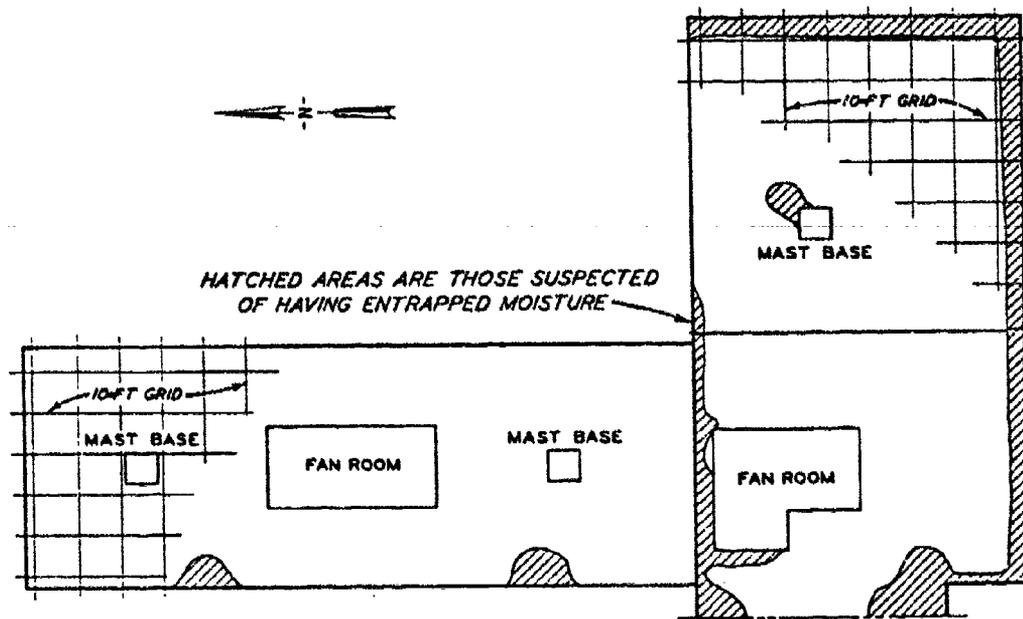


Figure 13. Illustration of possible format for recording roof conditions. Nuclear meter readings could be included for each grid intersection

Table 1
Nuclear Meters and Sources of Service

Equipment Manufacturers

CAMPBELL PACIFIC NUCLEAR CORP
130 South Buchanan Circle
Pacheco, California 94553
Tel (415) 687-6472

THE SEAMAN NUCLEAR CORP
3846 W. Wisconsin Avenue
Milwaukee, Wisconsin 53208
Tel (414) 342-1030

NUCLEAR INSTRUMENTS CORP
2300 W. Camden Road
Milwaukee, Wisconsin 53209

TROXLER ELECTRONIC LABORATORIES, INC
P. O. Box 12057, Cornwallis Road
Research Triangle Park,
North Carolina 27709
Tel (919) 549-8661

Sources of Nuclear Meter Surveys

RUPO TECHNICAL SERVICES, INC
Roof Maintenance Systems
8018 S. 27th Street
Oak Creek, Wisconsin 53154
Tel (414) 761-0270

GAMMIE NUCLEAR SERVICE CO
3737 Mt. Prospect Road
Franklin Park, Illinois 60131
Tel (618) 766-8770

THE MONROE COMPANY, INC
30801 Carter Street
Cleveland, Ohio 44139
Tel (216) 248-7890

NOTE: Information limited to that available at time of publication.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Link, Lewis E

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