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Low-Sloped Roofing Research Plan

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NBS Special publication

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ABSTRACT

This report presents a long-range plan for roofing research. The plan was developed in response to a need for roofing research addressing major materials problems and changes in low-sloped roofing materials technology. The intent of the plan is to establish the technical basis for developing standards and minimum levels of performance to assist in the selection of cost-effective and durable roofing materials. Four major areas of needed research are identified: (1) low-sloped roofing systems, (2) roofing membranes including single-ply and built-up, (3) thermal insulation for roofing systems, and (4) condition assessment and repair of roofs. Within each research area, a goal is given as well as a number of objectives to achieve the goal. A recommended approach to accomplish each objective is also given.

Key words: low-sloped roofing; mathematical modeling; membranes; repair; research plan; roofs; standards; thermal insulations.

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EXECUTIVE SUMMARY

This document presents a proposed long-range plan for research to provide the technical bases for standards for low-sloped roofing materials and systems. It is aimed at the development of needed measurement technology and largely addresses materials research. The plan was developed in response to a need for standard methods for evaluating the performance of new materials used in low-sloped roofing and for standards to provide the bases for their selection. A need also exists to develop the technical basis to evaluate methods for roof condition assessment and repair.

The United States inventory of low-sloped roofing is in the range of 25 to 30×10^9 ft^2 (2.3 to 2.8×10^9 m^2). Each year about 3×10^9 ft^2 (0.3×10^9 m^2) of low-sloped roofing is applied, divided somewhat equally between new roofing and reroofing of existing buildings. The annual costs for low-sloped roofing exceeds 10 billion dollars. The early failure rate (major and costly problems) for these types of roofs is considerably higher than for any other major component of a building. While roofing systems account for approximately 2 to 5 percent of the total cost of new buildings, they give rise to about 50 percent of building construction lawsuits.

A major change taking place in roofing membrane technology is the use of single-ply membranes as an alternative to built-up membranes. Over 100 single-ply membrane products by some 60 manufacturers are currently available. Consensus standards and minimum levels of performance for single-ply membranes have not been developed in the United States. A technical basis for their development is needed. Research in this area is given high priority.

Significant changes are also occurring in conventional bituminous built-up membrane technology. For example, the built-up roofing industry is experiencing an increase in the use of glass fiber mats (currently about 40 percent of total) as well as a gain in the use of polymer fiber reinforcements. Little data are available on the long-term performance of these new reinforcements used in built-up membranes. A technical basis for the development of standards for bituminous built-up membranes is needed.

Because of the wide variety of roofing materials and systems that are presently available and their variable in-service performance, including premature failure, criteria and appropriate test methods need to be developed to assist in the selection of materials and systems and in the prediction of their performance in service. The program goal is to develop the technical bases for increasing the performance and durability of low-sloped roofing materials and systems through the application of science and technology leading to the development of test methods and selection criteria suitable for incorporation in standards. Achievement of this goal will take many years and require the cooperation of roofing researchers from government, university, and industrial organizations.

The plan proposes that major research efforts be concentrated in the following categories:

- Theoretical analysis of roofing system performance and the development of models for predicting performance.

- Development of minimum levels of performance for roofing systems, membranes, and thermal insulation.

- Characterization of failure mechanisms of roof membranes and systems as a basis for understanding roofing performance and for advancement of roofing technology.

- The advancement of the in-situ condition assessment and repair of roofs by the application of measurement technology.

Four major areas for research for low-sloped roofing are covered in the plan, namely: (1) low-sloped roofing systems, (2) roofing membranes, (3) thermal insulations used in roofing systems, and (4) condition assessment and repair. Each of these areas contains elements of the major research effort outlined above. A possible flow scheme for conducting the proposed research is presented (see figure 2 in report). This flow scheme shows the relations between the proposed major activities and goals for the four research areas.

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1. INTRODUCTION

A long-range research plan for low-sloped roofing has been developed and is presented in this report. The major thrust of the plan is directed towards materials and systems research, and the application of measurement technology to roofing research.

Roofing research plans have been prepared by the U.S. Department of Energy (DOE) and the U.S. Army Corps of Engineers (COE). The DOE plan was concerned primarily with improving the thermal performance of roofing systems. A purpose of the COE plan was to foster coordination and avoid duplication of roofing research programs being carried out by Federal agencies. The DOE and COE plans were considered in the preparation of the present plan. The three plans complement each other.

1.1 NEED FOR ROOFING RESEARCH

The long-range plan presented here was developed in response to a need for roofing research addressing major roofing material problems and changes in low-sloped roofing materials technology. The need for research on low-sloped roofing also was identified in the report, "Summary of a Workshop on Low-Slope Roofing" [1], by the National Academy of Science's Advisory Board on the Built Environment. The DOE National Program Plan [2] for energy conservation in buildings also identified needed roofing research for materials and systems.

The United States inventory of industrial and commercial roofing (low-sloped) is in the range of 25 to 30 x 10^9 ft^2 (2.3 to 2.8 x 10^9 m^2). Each year about 3 x 10^9 ft^2 (0.3 x 10^9 m^2) of roofing is applied, divided about equally between new roofing and re-covering of existing roofs [3]. The annual costs for this roofing exceeds 10 billion dollars. The early failure rate for these types of roofs is considerably higher than for any other major element of a building. While roof systems account for approximately 2 to 5 percent of the total cost of buildings, they give rise to about 50 percent of building construction lawsuits [4]. Many of the failures are amenable to technological solutions which could result in significant cost savings.

A major change taking place in low-sloped roofing technology is the substitution of single-ply membranes for conventional built-up membranes. In 1975, single-ply membranes comprised about 2 percent of the membrane market, but it is forecast that these membranes will command over 30 percent of the commercial roofing market by 1985 [5]. Over 100 single-ply membrane products from about 60 manufacturers are currently available [6]. Consensus standards and minimum levels of performance for single-ply membranes have not been developed in the United States and a technical basis for their development is needed. Standards are needed to provide a reliable basis for the selection of cost effective durable materials. Research for single-ply membranes, therefore, is given high priority in the research plan.

Significant changes are also occurring in bituminous built-up membrane technology. For example, the built-up roofing industry is using more glass fiber mats as well as polyester and other polymeric reinforcements. Glass fiber mats may account for about 40 percent of the reinforcements used in built-up membranes [7]. In spite of over a century of use, voluntary consensus standards for completed built-up bituminous membranes do not exist. Such standards should be developed and research is needed to provide the technical basis for their development.

With the influx of the single-ply membrane materials into the roofing market and the changes occurring in bituminous roofing technology, a need exists for reliable durability test procedures to predict the long-term performance of these materials. ASTM Standard E 632, "Standard Practice for Developing Short-Term Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials," has been established to aid the complicated development of durability tests for any building material. The approach given in ASTM E632 outlines a rational approach which could assist the development of durability test procedures for single-ply and other roofing materials. Reliable durability data are essential for determining the life-cycle costs of roofing membrane materials.

Although the plan emphasizes needs for materials research for low-sloped roofing, it also recognizes that there are four essential elements to assuring the quality of good roof performance: (1) sound design, (2) quality materials, (3) good workmanship, and (4) good maintenance.

Steep roofing, e.g., residential roofing, is not covered by this research plan as significantly fewer problems are encountered with this type compared to low-sloped roofing. Some changes are taking place in the technology of roofing shingles. For example, fibrous glass in felted form is replacing traditional organic felts in the manufacture of shingles. Although such changes may necessitate some modifications in the ASTM standards for shingles, these changes are unlikely to require the level of research needed to establish standards for new membrane materials for low-sloped roofing.

1.2 PURPOSE OF PLAN

An important purpose of developing the long-range plan was to define areas of needed applied and fundamental research for low-sloped roofing. The plan stresses research which should contribute to significant improvements in the quality and performance of low-sloped roofing materials and systems. The intent is to establish the technical bases for developing standards and performance levels which will form the basis for the selection of cost-effective and durable roofing materials.

The plan presented here is broad and quite extensive. The achievement of its goals and objectives will take many years, requiring the joint efforts of all segments of the roofing community including industry, government, educational institutions, and standards-setting bodies. The plan recognizes and provides for the transfer of the results of roofing research from researchers to professional engineers, architects, designers, roofing contractors, roofing mechanics and building owners. The results of the research would be available to ASTM Committees and others which have responsibility for the development of standards for building materials and roofing system performance including C16 on Thermal Insulations, D8 on Roofing, Waterproofing, and Bituminous Materials, E6 on Performance of Building Construction, and G3 on Durability of Nonmetallic Materials. The research results would also be available to international organizations such as CIB* and RILEM** which recently formed a joint committee on single-layer roofing.

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* CIB--Conseil International du Batiment pour la Recherche d'Etude et la Documentation.

** RILEM--Reunion International des Laboratoires d'Essais et de Recherches sur les Materiaux et les Constructions.

2. ROOFING TRENDS

The long-range plan for roofing research is based on predictions of technological developments and trends in the roofing industry over the next decade. The predictions are based on published market surveys, information from trade associations (for example, National Roofing Contractors Association, Asphalt Roofing Manufacturers Association, Urethane Foam Contractors Association, and Single-Ply Roofing Institute), and projections based on the history of the roofing industry. Predictions regarding materials used in low-sloped roofs are:

- Low-sloped roofing construction will continue at an annual rate of about 3×10^9 ft^2 (0.3×10^9 m^2) per year at an applied cost of over 10 billion dollars. This dollar figure is expected to increase in the future.

- Application of new roofing and reroofing or re-covering work will each continue to account for about 50 percent of the total market during the coming decade.

- Problems with low-sloped roofing systems requiring costly maintenance, repair, and replacement by owners will continue at about the same relatively high rate [8] during the decade.

- Single-ply roofing will command at least 30 percent of the low-sloped roofing market in 1985 with an application of over 1×10^9 ft^2 (0.1×10^9 m^2) at an installed cost of about 3 billion dollars. Although the amount of single-ply materials used will steadily increase, the number of products is expected to decline during the decade.

- Serious problems may result in using single-ply materials if test methods, criteria, standards, and quality assurance programs are not developed to provide a reliable basis for material selection.

- The use of conventional multi-ply bituminous built-up roofing will decline to about 60-70 percent of the market by 1985.

- The bituminous built-up roofing industry will experience a large increase in the use of glass fiber mats as well as a modest gain in the use of polyester and other polymer fiber reinforcements.

- The use of the more thermally efficient roof insulations (for example, expanded polystyrene and polyurethane foams) will increase, while the use of the more conventional board type insulations (fibrous glass and mineral board) will decrease.

- Computer-aided design (CAD) will become increasingly important in the design and construction of roofing systems. The recent advances in computer science and technology have resulted in significant advances in the understanding of the performance of building materials and systems and will help increase the understanding of the performance of roofing systems.

The influences of economic and social issues on roofing trends also were considered, including:

- The need to conserve energy and to find substitutes for materials which may be in short supply will lead to the development of new materials for roofing use.

- Increased rehabilitation of buildings will result in the need for reliable methods, including non-destructive evaluation, to predict the condition of roofing materials, and to evaluate the remaining service life of in-place materials.

- Increased costs of labor may necessitate the use of less labor-intensive techniques for roofing installation.

3. PROGRAM GOAL STATEMENT

To develop the technical bases for increasing the performance and durability of low-sloped roofing materials and systems through the application of science and technology leading to the development of test methods and selection criteria suitable for incorporation in standards.

4. OUTLINE OF RESEARCH IN THE LONG-RANGE PLAN

The long-range plan covers four research areas for low-sloped roofing:

1. Low-sloped roofing systems
2. Roofing membranes
   a. Single-ply roofing membrances
   b. Built-up roofing membranes
3. Thermal insulations used in roofing systems
4. Condition assessment and repair

Under each research area a goal has been stated. Following the goal statement, a brief narrative is generally provided to indicate the problems to be solved, the research approach, the products, the implementation of the research results and the impact in the roofing industry. The narrative is followed by a set of objectives for tasks to be performed in meeting the goal. A brief rationale is given for each objective followed by recommendations for the required research. A summary of the goals for each of the four research areas is given in table 1.

As presented in the following sections of the report, each of the four research areas is intended to stand alone with limited cross-referencing between them. As a consequence, some parallelisms exist between the research suggested in each of the four areas. The thrusts of the research efforts are concentrated in the following categories.

- Theoretical analysis of roofing system performance and the development of models for predicitng performance.

- Development of minimum levels of performance for roofing systems, membranes, and thermal insulation.

- Characterization of failure mechanisms of roof membranes and systems as a basis for understanding roofing performance and for advancement of roofing technology.

- The advancement of in-situ condition assessment and repair of roofs by the application of measurement technology.

A conception of the efforts which may be required in developing minimum levels of performance for roofing systems, membranes, and thermal insulation qan be obtained from examining table 2. Performance attributes (characteristics) are listed for systems, membranes, and thermal insulations as reported in two NBS publications: Building Science Series 55 on bituminous membranes [9], and Technical Note 972 dealing with single-ply membranes [10]. The closed circles in table 2 indicate attributes for which preliminary minimum levels of performance have been suggested. It is evident that preliminary levels of performance are lacking for the majority of the performance attributes for both single-ply and bituminous membrane roofing. Also, no performance attributes pertaining to thermal insulation were listed in these NBS reports. In examining table 2, questions may be raised such as whether the list of suggested

Table 1. Areas of Needed Research and Goals

Area of Needed Research	Goal
1. Low-Sloped Roofing Systems	To develop an improved understanding of the factors controlling the performance of roofing systems using material science and engineering mechanics concepts; and to develop relationships between properties of the roofing materials and performance of the roofing systems.
2. Roofing Membranes	
a. Single-Ply Roofing Membranes	To develop a technical basis for establishing standards and minimum performance levels for single-ply roofing membranes.
b. Bituminous Built-Up Roofing Membranes	To advance the state-of-the-art of bituminous roofing membrane technology by developing methods for determining minimum performance levels and developing improved methods for evaluating and predicting the performance of these membranes.
3. Thermal Insulation Used In Roofing Systems	To develop a technical basis for establishing minimum performance levels for roofing insulation materials considering the thermal and mechanical performance and design of insulated roofing systems.
4. Condition Assessment and Repair of Roofs	To develop a technical basis for roof condition assessment and for the evaluation of repair techniques.

Table 2. Suggested Performance Attributes for Single-Ply and Bituminous Membranes.

Suggested Performance Attribute	Reference Which Lists Attributes*		Suggested Minimum Levels of Performance**	
	BSS 55	TN 972	Single-Ply	Built-up
<u>Roofing Systems</u>				
Wind (Uplift) Resistance	√	√	●	●
Fire (Flame) Resistance	√	√	●	●
Punching Shear	√	√	●	●
Impact (Hail) Resistance	√	√	●	●
Durability (Weather Resistance)	√	√	●	
<u>Roofing Membranes</u>				
Tensile Strength	√	√		●
Flexural Strength	√			●
Thermal Expansion	√	√		●
Thermal Shock Resistance	√			●
Tensile Fatigue Strength	√	√		●
Flexural Fatigue Strength	√			●
Ultimate Elongation		√		
Moisture Effects on Strength	√	√		
Moisture Expansion	√	√		
Permeability	√	√		
Notch Tensile Strength	√			
Creep	√	√		
Ply Adhesion	√	√		
Abrasion Resistance	√	√		
Tear Resistance	√	√		
Pliability	√	√		
Seam Strength		√	●	
Fungus Attack Resistance	√	√	●	
Chemical Resistance		√	●	
Color Stability/Reflectivity		√		
<u>Roofing Thermal Insulations</u>				
(No performance attributes listed in cited publications)				

* The check-mark indicates that the performance attribute was listed in NBS Building Science Series (BSS) 55 on bituminous membranes [9] or NBS Technical Note (TN) 972 on single-ply membranes [10].

** The Closed Circles Indicate Those Attributes for Which Preliminary Minimum Levels of Performance Have Been Suggested.

attributes for each of the categories (systems, membranes, and insulation) is complete or excessive, what data and analyses are needed to recommend performance levels where none exist, and does a theoretical basis exist to support the previously suggested minimum levels of performance. One reason for the development of this research plan was to address such questions on roofing performance.

5. RESEARCH AREAS

5.1 LOW-SLOPED ROOFING SYSTEMS

Goal: To develop an improved understanding of the factors controlling the performance of roofing systems using material science and engineering mechanics concepts; and to develop relationships between properties of the roofing materials and the performance of the roofing system.

Comments: The roofing system can be treated in terms of the individual components of which it is composed. However, in its simplest form, this approach does not consider the effects of interactions between components on the ultimate performance of the system. Study of the entire system is necessary to provide insights into the interactions which are important to system performance. The typical low-sloped roofing system has three major interacting components: structural deck, thermal insulation, and waterproofing membrane. Vapor flow retarders, when used, and roof flashings, must also be considered in studying the system as a whole. The distribution of attachments and penetrations and their effect on system performance should also be considered.

Of major concern to the roofing community is the technical complexity of the modern roofing system [11]. The proliferation of materials and design combinations involving decks, thermal insulations, and membranes often creates unexpected adverse interactions between these components resulting in unacceptable performance of the roofing system. It is not practical to conduct extensive laboratory and field tests in order to predict the performance of each combination which may be assembled in service. A technical approach to overcoming these problems is the use of validated mathematical modeling to predict performance of selected combinations of materials and designs in a roofing system [12]. Modeling would facilitate the acceptance of new materials and innovative designs. Once a model has been developed, it is essential that the validity of the model be verified by testing roofing specimens under known conditions and by field tests on actual roofs.

The availability of mathematical models to all segments of the roofing industry will be a large step toward providing an improved technical basis for evaluating roofing performance and for establishing minimum levels of performance for important materials properties. Mathematical models can be a valuable tool in assisting the manufacturing segment and the design profession in specifying and assembling compatible material combinations for use in decks, insulations and membranes. Another important use of mathematical models will be in computer-aided design [13].

5.1.1 Objective 1--Identification of Failure Modes

Objective: To obtain and analyze information on the in-service performance and failure modes of low-sloped roofing systems.

Comments: Analysis of information on in-service performance and field failures of roofing systems and materials will form, in part, the basis for the development of models described in the following objective and for the development of simulative accelerated durability tests. It is anticipated that the needed data will be obtained from organizations such as the National Roofing Contractors Association (NRCA) and the newly established University of Maryland Architecture and Engineering Performance Information Center (AEPIC).

Recommended Approach:

- Analyze data obtained from industry associations (NRCA, AEPIC), contacts with technical experts, and by field inspections; relate problems to causes, for example, is it a material durability problem or a design problem?

- Identify probable failure mechanisms; for example, is failure due to deterioration of a single material or to incompatibility between or among roofing components, or the constituents of a composite material?

- Document relations between failure mechanisms and premature problem manifestations.

5.1.2 Objective 2--Development of Mathematical Models

Objective: To develop mathematical models which describe essential aspects of total roofing system performance and simulate interactions between and among the various components of the low-sloped roofing system.

Comments: To provide many years of satisfactory service, a roofing system must be capable of withstanding the environmental and service stresses to which it will be subjected. Examples of such stresses include temperature, moisture, UV radiation, wind, hail (impact), foot traffic, and building movement. Empirical testing of systems comprised of any of the many available roofing materials, particularly the multitude of newer ones entering the market, does not provide adequate information for prediction of performance. Such testing is costly and time consuming and incapable of evaluating all materials in all roofing designs. Moreover, empirical testing of new materials may discourage their use because of the expense involved in testing. In principle, mathematical modeling offers a much more cost-effective and broadly-applicable approach to understanding the ability of a roof system to resist the stresses impressed upon it and the ability of the individual components to interact compatibly. Modeling also provides a means of identifying important performance properties and establishing minimum levels of performance for those properties.

Although some mathematical modeling of roofing performance has been accomplished, the models do not, in general, deal with total system performance [12]. Models describing total system performance should be developed. Total system models should be structured so as to be easily understood and readily modified by developing and linking together well-documented submodels describing specific aspects of roofing performance.

Recommended Approach:

- Define satisfactory roofing performance and modes of failure of roofing systems to be described by mathematical modeling; identify environmental and mechanical stresses which affect system performance and the specific modes of failure.

- Develop mathematical relationships (submodels) between specific failure mechanisms and measurable properties of the roofing materials in order to describe the ability of the roofing system to resist failure.

- Where possible, use available data for comparison with the results of the submodels; revise the submodel as necessary to achieve agreement between the submodel results and available test data.

- Combine submodels to develop a model for predicting the roofing system performance.

- Develop relationships which can be used in computer-aided designs for roofs, and provide recommendations for system design and materials selection based on results of the modeling.

- Develop relationships for calculating minimum performance levels for materials and systems based on roof design.

5.1.3 Objective 3--Validation and Revision of Mathematical Models

Objective: To compare the results from the models with the results of laboratory and field testing, and where necessary, revise the models.

Comments: A mathematical model gains credibility after validation against the results of laboratory and field testing. A large gap may exist between the performance predicted from a theoretically developed model and what actually occurs on the roof. As an intermediate validation, a model can be tested under simulated service conditions in the laboratory. It is envisioned that relatively large (for example, 10 x 10 ft or 3 x 3 m) specimens of complete roofing systems may be necessary for model validation in the laboratory. The next step is to move from the laboratory to the field; these studies could be carried on either concurrently or sequentially. The models can also be tested by measuring the performance of real systems under known weather conditions. The results of the simulations may be used to revise the models whenever necessary.

Recommended Approach:

- Conduct laboratory tests using large specimens exposed under controlled and cyclic environmental conditions in appropriate test chambers; where necessary, develop appropriate test apparatus and instrumentation.

- Conduct appropriate field tests of roofs; characterize the service environment, building movements, and the changes in roofing performance.

- Compare theoretical results predicted by the models with those of the laboratory and field tests and revise the models as necessary.

- Prepare and publish papers and reports which document the models and demonstrate the usefulness of the modeling approach to roofing designers.

5.2 ROOFING MEMBRANES

This section presents needed research for both single-ply and bituminous built-up membranes. They comprise over 95 percent of the waterproofing membranes for low-sloped roofing systems. Ideally, performance standards should be developed applicable to all types of membranes for low-sloped roofing. Although the research needs for the two types of membranes are presented separately, the intent of the proposed research is to provide the basis for the establishment of standards applicable to all membranes.

In typical roofing design, the waterproofing membrane is placed on the insulation. In contrast, for protected membrane roofing, the membrane is placed below the insulation. In this case, the insulation provides protection to the membrane from the effects of weather. The research proposed for membranes will consider both types of roofing design.

5.2.1 Single-Ply Roofing Membranes

Goal: To develop a technical basis for establishing standards and minimum performance levels for single-ply roofing membranes.

Comments: Since the mid-1970s, a rapid increase in the use of sheet-applied single-ply membranes has occurred. In 1982, there were over 100 sheet-applied single-ply roofing products manufactured and distributed by about 60 manufacturers in the U.S. A number of these products were from various European countries as well as from Australia, Canada, and Japan.

Unlike the more traditional roofing materials, sufficient information is not available to indicate the reliability of single-ply membranes to perform adequately under the broad extremes of U.S. climatic conditions in buildings constructed using U.S. building practices. Long-term field performance experience in the U.S. is also lacking for most of the materials. Serious premature failures have occurred with some products. To avoid an increase in the incidence of premature failures, meaningful standards need to be developed and accepted to aid materials selection. Fear of failure could become a barrier to the use of new materials for which standards do not exist. Establishment of meaningful standards and test methods would provide a sound basis for material selection. This requires the development of the technical basis for the needed standards.

The emphasis will be on laboratory research directed toward identifying failure modes and mechanisms, measurement methods for characterizing classes of single-ply membranes (particularly with regard to performance properties used in mathematical models), as well as the development of test methods and methods for the determination of performance levels for incorporation into voluntary consensus standards.

Field studies are also needed to identify failure mechanisms and the level of performance under characterized service environments. Failure mechanisms also may be identified in collaborative studies with industry associations such as the NRCA. Also, it is expected that data on failures can be obtained from the AEPIC performance data described in Objective 1 under Roofing Systems (section 5.1.1).

5.2.1.1 Objective 1--Definition of Performance Attributes

Objective: To define performance attributes of single-ply roofing membranes based on existing information such as field performance, research results, test methods, and standards.

Comments: An important first step in developing standards and minimum levels of performance for single-ply membranes is to identify the properties and performance attributes which the membrane must have and retain in order to provide a watertight component of the roofing system for the intended service life of the roof. Since the widespread and rapidly-growing use of single-ply materials has occurred, much information has been generated around the world by organizations such as research laboratories, government agencies, standards-setting bodies, and trade associations. This information should be assembled and collated to help define preliminary performance attributes. Such a study would also provide a basis for setting priorities for conducting research needed to support the development of standards for single-ply materials. In addition the study would help identify failure mechanisms of single-ply membranes. Thus, it could be used, in part, as the basis for mathematical models for membrane and system performance.

Recommended Approach:

- Obtain available domestic and foreign standards from such standards bodies as ASTM (US), DIN (Germany), AFNOR (France), BSI (UK), CGSB (Canada), and others.

- Review these documents and other literature for applicable information on specified performance levels, measurement methods, environmental factors, accelerated weathering techniques, and mathematical modeling procedures which may apply to the measurement of properties and the prediction of performance of single-ply membranes.

- Obtain data on materials properties and documentation on in-service performance, as well as laboratory information on alleged failure mechanisms and their relationship to field performance.

- Conduct a workshop on defining performance attributes for single-ply membranes.

- Review existing test procedures for determining membrane attributes and provide recommendations for needed test method development.

- Prepare report on applicable attributes.

5.2.1.2 Objective 2--Characterization of Failure Mechanisms

Objective: To identify and characterize mechanisms involved in premature failures experienced in single-ply membranes and seams under service conditions.

Comments: Elastomeric, plastomeric and modified bituminous materials which are used in single-ply membranes undergo chemical, physical, and mechanical property changes when exposed to degradation factors such as UV radiation, moisture, temperature, and mechanical stress. The rates of change depend on the intensity of the exposure and the synergism among the factors. An end result is that changes occur which decrease the membrane's ability to perform its essential function of keeping the roof watertight. For example, seams in membranes may open. Characterization of bonded seams and identification of their failure mechanisms is particularly important, since seams have been the source of many premature failures of single-ply membranes [14]. A basic knowledge of failure mechanisms which occur in the three classes of single-ply membranes will greatly assist in improving performance through design guidelines, and material design. Further, this knowledge will contribute to the development of test methods and minimum levels of performance. It is important to note that unacceptable performance may be due not only to poor resistance to the service environment, but also to material flaws already present or introduced at the time of installation.

Recommended Approach:

- Develop hypotheses of failure modes based on an analysis of the data on failed (exposed) and control (unexposed) specimens.

- Characterize seam interfaces and identify modes of failures for bonded seams.

- Characterize original and failed specimens mechanically, chemically, and microstructurally to determine mechanisms of degradation and the extent of changes which occurred during exposure.

- Characterize failed membranes in terms of failure patterns (for example, tearing, puncturing, splitting) including shape, orientation, and density of microcracks or microtears.

- Field expose membrane samples with seams to well-characterized service environments in statistically-designed experiments.

- Expose samples having seams to accelerated environmental testing procedures employing various realistic combinations of radiation, moisture, temperature, and mechanical stress. The procedure described in ASTM E 632 will be followed.

- Measure changes which occur and analyze data with respect to degradation mechanisms and the rates of the degradation processes.

- Develop analytical relationships consistent with the degradation mechanisms and the rates of degradation.

- Prepare report on research findings.

5.2.1.3 Objective 3--Methods for Characterizing Membrane Properties

Objective: To develop methods for characterizing the important properties of single-ply membrane materials and seams.

Comments: As mentioned, there are over 100 products currently available in the marketplace being promoted as useful for single-ply roof membranes. A first step in setting forth technical information and data on the performance characteristics of these materials is to develop methods for characterizing the pertinent chemical, physical, and mechanical properties which are critical to the performance of these materials under in-service conditions. Mathematical modeling of system performance (section 5.1.2) could be used as a means of identifying the important properties which should be measured.

Recommended Approach:

- Identify those properties which are critical to the long-term performance of single-ply membranes under service conditions. Develop mathematical models describing performance under service conditions to identify those properties required for acceptable performance.

- Develop, as necessary, techniques for measuring the mechanical, physical, and chemical properties identified above.

- Prepare report describing test methods for characterizing the properties of materials important to their performance in a roofing system.

- Submit draft standard test methods for characterizing single-ply membranes and seams to standards-writing organizations such as ASTM.

5.2.1.4 Objective 4--Evaluation of Service Life

Objective: To develop methods and measurement techniques to evaluate and predict the service lives of single-ply roofing membranes and seams.

Comments: On-the-roof experience has suggested that failure at seams has been a major problem with single-ply membranes. It must be remembered that the roofing membrane is the waterproofing component of the roofing system. Therefore, in evaluating or predicting a membrane's service life, not only should its material properties be included, but also integrity of the entire membrane must be considered. To ensure this integrity over the service life of the roof, seams located where sheets overlap either in the field of the roof, or at the perimeter and other projection flashings must remain watertight over the service life of the membrane. Therefore, test methods based on adhesion theory should be developed to predict the field performance of seams as well as methods for the prediction of the durability of the materials themselves.

Obviously a roofing membrane should retain its critical properties above a certain level over the life of the roof. To predict service life, accelerated weathering tests are required which realistically simulate exposure environments. The methodology given in ASTM E 632 should be followed in developing the accelerated weathering tests. Figure 1 presents a flow chart of the recommended procedures given in ASTM E 632 for developing predictive service life tests. The test results could be used in demonstrating the application of the reliability approach in making service-life predictions.

Recommended Approach:

- Apply theories of adhesion of polymeric materials to understanding factors controlling the performance of seams of single-ply membranes.

- Apply principles and procedures described in ASTM E 632 to service life prediction of single-ply membranes including seams.

- Modify existing test methods and develop new test methods as required for use in service life predictions.

- Identify or develop accelerated weathering apparatus and environmental simulation chambers as needed for testing.

- Conduct test program using selected samples with bonded seams of the three classes of single-ply membrane materials.

- Develop mathematical models based on the application of ASTM E 632 to relate deterioration rates of membranes and seams to their properties.

- Demonstrate the prediction of the service life of single-ply membranes and seams using statistically-designed experiments.

- Prepare draft test methods on the prediction of membrane and seam service life for submittal to ASTM and other standard and specification writing groups.

5.2.1.5 Objective 5--Minimum Levels of Performance

Objective: To develop methods for determining or calculating minimum levels of performance for single-ply membranes and seams based on the roofing design.

Comments: In the application of the performance concept to any building material or system, a critical factor is the identification, in quantitative terms, of minimum acceptable levels of performance. It would be desirable that one set of performance levels might suffice for all single-ply membranes and all designs. Considering the demand imposed by different roof designs and exposures, this does not appear to be possible. The type of membrane and roofing design should be considered as well as its service environment and the method of membrane application, i.e., loose-laid, fully adhered, or partially adhered. Next, the minimum performance levels of seams must be identified. The minimum performance levels should apply not only to initial performance, but to performance over the expected lifetime of the roof.

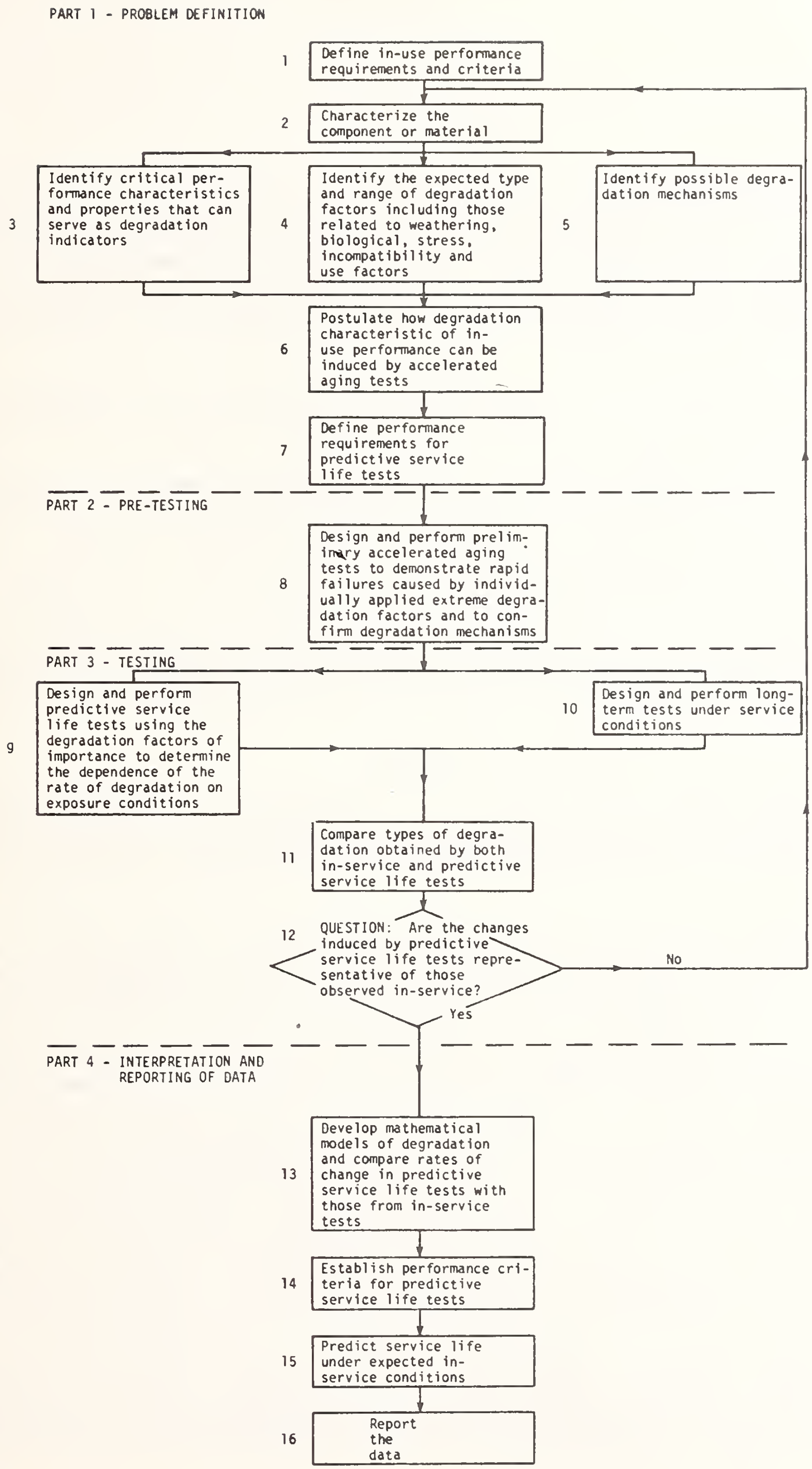


Figure 1. Recommended procedure given in ASTM E 632 for developing predictive service life tests

Recommended Approach:

- Determine the performance history under service conditions of the various classes of single-ply membranes from literature and field surveys.

- Relate failure modes and mechanisms identified in section 5.1.3, (Objective 3) to performance history.

- Identify critical attributes and their relation to failure modes and field performance history.

- Analyze the data obtained from the test method development objective (Objective 4, section 5.2.1.4) by modeling and other methods to develop a basis for determining or calculating minimum performance levels.

- Review conclusions with experts in private and public sectors.

- Publish methods for determining or calculating minimum performance levels for the various classes of membranes with seams, considering the methods of attachment, the service environment, and roofing design.

5.2.2 Bituminous Built-Up Roofing Membranes

Goal. To advance the state-of-the-art of bituminous roofing membrane technology by developing methods for determining minimum performance levels and developing improved methods for evaluating and predicting the performance of these membranes.

Comments: For over a century the multi-ply bituminous roofing membranes have been used as the principal waterproofing component of low-sloped roofing systems in the U.S. Traditionally, the composite membrane has consisted of two to five plies of reinforcing felts or fabric adhered to each other on the job-site with a thermoplastic bituminous adhesive. The felts or fabrics are composed of a variety of bituminous impregnated fibers such as cellulose, asbestos, fibrous glass, and more recently, polymeric fibers. The adhesive is either petroleum asphalt or coal-tar bitumen. These components of the membrane are described in prescriptive material specifications promulgated by ASTM and others. However, until 1974, in spite of over a century of use required performance properties of the bituminous roofing membranes had not been developed. In 1974, NBS published a research report [9] suggesting preliminary performance criteria for bituminous membrane roofing. Although this document was regarded as a major step in advancing the state-of-the-art of roofing technology, it was a preliminary effort to describe membrane roofing in performance language. Specifically, many of the performance levels were empirically determined and did not consider different roofing designs. The research proposed in this section builds on the past research to update the performance criteria of bituminous membrane roofing, and to provide a fundamental basis for developing the minimum levels of performance.

In most cases, the problems with bituminous built-up roofing are well known [15]. Examples of such problems include blistering, splitting, ridging, slippage, and ply-delamination. Many of these problems are undoubtedly amenable to technological solutions, once the technological knowledge can be translated into practical guidelines, specifications and standards for implementation by manufacturers, specifiers, and applicators. The impact of using a scientific and technological basis to attain increased performance can be large, since the forecast for use of these membranes through the mid-1980s is of the order of 2×10^9 ft^2 (0.2×10^9 m^2) each year.

5.2.2.1 Objective 1--Characterization of Built-Up Membranes

Objective: To develop the technical basis for characterizing bituminous built-up roofing membranes and to characterize their failure mechanisms.

Comments: Roofing membranes are intended to have service lives of 25 years or more. Although the majority of built-up membranes perform satisfactorily, premature failures are common. To better understand the performance of these membranes, methods are needed for their characterization. Information is also needed on the factors contributing to premature failures and on failure mechanisms of built-up membranes. This information will be valuable in making service-life predictions of built-up membranes and in understanding their performance.

Recommended Approach:

- Develop methods to characterize built-up membranes with regard to interactions between the bitumen and reinforcing fabric, and determine modes of deformation, degradation, and stress build-up.

- Based on modes of in-service failures of built-up membranes, develop relationships between their failures, materials properties, and environmental service stresses including, for example, the effect of moisture.

- Characterize failed membranes in terms of failure patterns (for example, tearing, puncture, splitting) including shape, orientation, and density of microcracks or microtears.

- Develop relationships between environmental and mechanical stress and the fracture mechanics properties of built-up membranes using accelerated weathering techniques.

- Develop analytical models relating the failures of membranes to their composition and microstructure under in-service environments and mechanical stresses. Test the models against laboratory data.

- Develop accelerated durability tests which produce the same failure processes that occur in the field. Prepare draft standards incorporating these accelerated durability tests and submit them to ASTM.

5.2.2.2 Objective 2--Minimum Levels of Performance

Objective: To analyze existing minimum levels of performance for bituminous built-up roofing membranes and develop methods for determining performance levels needed in current and future roofing designs.

Comments: Twenty attributes which a built-up membrane should possess have been identified. Test methods and minimum acceptable performance levels for nine of these attributes have been proposed. Although there has been a considerable improvement in the performance of built-up membranes, premature failures continue to occur at an unacceptably high rate. A need exists to reexamine and possibly modify existing minimum levels of performance and test methods for bituminous membrane roofing. Further relationships need to be developed to determine minimum performance levels for specific roofing designs.

Recommended Approach:

- Obtain data and information (for example, NCRA's Project Pin Point and AEPIC) on problems with built-up roof membranes.

- Analyze the test methods and minimum performance levels given in the NBS preliminary performance criteria [9] with respect to their applicability to current and future bituminous membrane technology and roofing designs.

- Using the above-listed data and information, combined with the results of the mathematical models developed in section 5.2.2.1 (Objective 1), identify additional attributes for which minimum levels of performance needed to be determined.

- Identify test methods, modify existing methods if necessary, or develop new ones to characterize the important properties of built-up membranes not included in the NBS preliminary performance criteria [9].

- Develop relationships to assist in determining minimum performance levels for specific designs.

- Submit newly developed test methods to ASTM for consideration as standard test methods.

5.2.2.3 Objective 3--Characterization of New Materials

Objective: To develop methods for characterizing new materials used in the fabrication of bituminous built-up membranes.

Comments: During the past decade a number of materials have entered the built-up roofing marketplace as replacements for the traditional reinforcing felts or fabrics. Fibrous glass technology has resulted in felts being produced by three different processes, one wet and two dry. New light-weight polyester based reinforcements have been introduced that are described as having desirable properties conducive to improved roofing membrane performance. Changes have also occurred with asphalt materials which are being modified with elastomers to improve their performance in bituminous membrane roofing. Methods for characterizing these new materials are needed.

In addition, the roofing industry has begun to recognize the limited applicability of empirical consistency tests such as softening point, penetration, and ductility to describe the rheological properties of roofing bitumens. The measurement of viscosity would provide an improved method of specifying roofing asphalts. Viscosity is a rheological property describing a fluid's resistance to flow. For roofing bitumens, viscosity not only pertains to flow but reflects indirectly the adhesive characteristics. These characteristics in turn have been related to bituminous roofing membrane failures such as splitting, blistering, and sliding. Reliable test methods for both laboratory and field use are needed for measuring the rheological properties of roofing bitumens at application and service temperatures.

Recommended Approach:

- Analyze available information on material properties, application specifications, and in-service performance of membranes constructed from the new materials to identify needs for test methods for their characterization.

- Develop measurement techniques needed for characterizing new materials and develop the technical bases for needed test methods for measuring the performance properties of new materials.

- Perform accelerated weathering studies to compare the service-life of roofs constructed with new materials with those of traditional materials. The methodology given in ASTM E 632 should be followed.

- Develop test methods for both laboratory and field use for determining asphalt viscosity at application and service temperatures.

- Develop the technical basis for a new ASTM specification for classifying roofing asphalts using fundamental rheological properties as the performance requirements in lieu of the empirical measures of flow characteristics now used.

5.3 THERMAL INSULATION USED IN ROOFING SYSTEMS

Goal. To develop a technical basis for establishing minimum performance levels for roofing insulation materials considering the thermal and mechanical performance and design of insulated roofing systems.

Comments: The total proportion of low-sloped roofs which have thermal insulation as a component is about 80 percent. There are many types and thicknesses of insulation available in the marketplace. They vary from the cellulosic fiberboard types to more thermally efficient materials such as the polymeric foams. Their use is not limited to new roofing as a considerable amount is employed in improving the thermal efficiencies of existing roofs. These insulations, in board form, are used in conjunction with both the multi-ply bituminous built-up membranes and with the single-ply membranes. In addition, polyurethane foam insulation is applied as a component of a sprayed-in-place roofing system.

The insulations perform their major function of restricting heat flow in or out of the building as long as they remain in a relatively dry condition. Moisture accumulation in insulations is not the only manner by which insulations may adversely affect roofing performance. Insulations can affect the level and distribution of stresses in the roofing membrane. This, in turn, may shorten membrane life or cause early failure if the system is designed improperly or applied incorrectly. The problems associated with insulated roofing systems are well known [16] and the impact of these problems in terms of wasted energy and premature failure of roofing systems are recognized by the roofing industry. However, neither the mechanisms of failure nor the relation of insulation properties to the observed problems have been adequately studied. The identification of failure mechanisms and the characterization of the important properties of insulations are necessary for determining the influence of thermal insulations on the roof system performance. Further, methods need to be developed to assist in determining the minimum performance levels of thermal insulation for specific roof designs.

5.3.1 Objective 1--Characterization of Insulation Properties

Objective: To develop measurement techniques for characterizing the important properties of roof insulation materials.

Comments: Some of the insulation types which are currently available include: 1) fiberboard, 2) perlite, 3) fibrous glass, 4) foam glass, 5) polyurethane foam, 6) expanded and extruded polystyrene, and 7) phenolic foams. Also, two or more of these materials are often laminated into what is referred to as composite board insulations. To understand and predict their performance both thermally and mechanically, important properties must be characterized. This objective is not only concerned with the identification and measurement of the initial properties of insulation materials but also with the changes which occur upon aging under service conditions.

Recommended Approach:

- Identify the important properties of thermal insulations which control their performance and durability in roofing applications. They may be identified, in part, based on the results from solving mathematical models for roofing systems (section 5.1).

- Develop measurement techniques needed for characterizing the important properties of thermal insulation, and the effect of moisture migration through the roofing system on the insulation properties.

- Develop accelerated aging test methods and use them to determine the effects of aging on the properties of the insulations including durability, mechanical and thermal properties, and fire resistance.

- Prepare research reports on the methods for characterization of roof insulation materials and submit the methods to ASTM for possible inclusion in insulation standards.

5.3.2 Objective 2--Minimum Levels of Performance

Objective: To develop the technical basis for establishing minimum levels of performance for roof insulation materials based on roofing design.

Comments: In spite of over 70 years use of thermal insulations in low-sloped roofing systems, insulation materials are specified only by prescriptive specifications. With the exception of thermal transmittance, performance levels are not given nor has a technical basis been developed for determining performance levels based on roofing design.

Recommended Approach:

- Analyze field performance data and information regarding roof failures attributed in full or in part to roofing insulations; identify their major properties and aging characteristics that play a role in failure processes.

- Develop accelerated durability tests which simulate failure mechanisms occurring in service, and which would provide the basis for making realistic service life predictions and assist in determining minimum levels of performance.

- Develop relationships to assist in determining mimimum performance levels for thermal insulation based on roof design.

- Prepare a report on methods for determining minimum performance levels based on design.

5.3.3 Objective 3--Sprayed-in-Place Foam Insulation Roofing Systems

Objective: To develop the technical basis for the development of test methods for determining minimum levels of performance for sprayed-in-place foam insulation roofing systems.

Comments: Sprayed-in-place polyurethane foam (SPUF) roofing systems have been used for over 15 years as an alternative to the more traditional types of roofing systems used on low-sloped or sloping decks. The systems consist of a layer of polyurethane foam insulation sprayed on a suitable substrate. A protective coating (liquid-applied) is applied to the foam to provide weatherproofing.

In 1973, NBS published suggested guidelines for the selection and use of these systems [17]. A set of preliminary minimum levels of performance together with appropriate test methods were also provided to identify acceptable materials. Performance attributes for sprayed-in-place foam insulation roofing included fire safety, wind resistance, water resistance, stress resistance, impact resistance, dimensional stability, and coating durability. Over the past decade, significant advances in the technology of polyurethane foam roofing systems have occurred. Further, considerable research concerning system performance and the protective coatings has been conducted by several laboratories. The results of these research activities should provide the starting point for the determination of minimum levels of performance. It is anticipated that industry associations such as the Urethane Foam Contractors Association (UFCA) could provide information concerning performance and mechanisms of failure in service. Minimum performance levels should consider the possibility of the development of sprayed-in-place roofing systems incorporating insulation other than polyurethane.

Recommended Approach:

- Analyze existing information including the previously suggested minimum performance levels and the results of previously conducted research as the basis for determining revised levels of performance.

- Develop, as needed, measurement techniques for characterizing sprayed-in-place polyurethane foam roofing systems.

- Identify and conduct laboratory and field research needed to provide information necessary for the determination of minimum levels of performance.

- Develop accelerated aging procedures (using the practice given in ASTM E 632) to predict the service life of protective coatings used in these systems.

- Prepare a draft document containing minimum levels of performance and submit it to ASTM for consideration as a standard for sprayed-in-place polyurethane foam roofing systems.

5.4 CONDITION ASSESSMENT AND REPAIR OF ROOFS

Goal: To develop a technical basis for roof condition assessment and for the evaluation of repair techniques.

Comments: Determination of the condition of roofing materials and systems is needed to make decisions on the need for repair, the type and extent of needed repairs, and whether the roof should be replaced. Condition assessment of roofs is based largely on visual inspections, which give little information on the sub-surface condition of the roof. Further, it is difficult to locate leaks in a membrane by visual examination. The increased use of non-destructive evaluation (NDE) techniques should greatly improve the information obtained in roofing inspections. A technical base, however, needs to be developed for facilitating the interpretation of the results of NDE inspections.

Roofing repairs most often involve the membrane. Several years ago, guidelines were prepared for the repair of built-up membranes [18]. However, significant advances have since been made in materials which should be incorporated into the guidelines. In addition, the repair of single-ply membranes needs to be addressed. Guidelines for effective repairs should be based on an understanding of the failure mechanisms and on the factors controlling the performance of repair materials.

In the following two objectives, single-ply membranes and built-up membranes are considered separately. It is anticipated that different methods will be needed for repairing the various types of single-ply sheets and seams and built-up membranes.

5.4.1 Objective 1--Condition of Single-Ply Roofing Systems

Objective: To develop measurement techniques and guidelines for the diagnosis of problems involving single-ply membranes and for evaluating maintenance and repair methods applicable to these membranes and systems.

Comments: As previously discussed, a wide variety of polymeric materials are being used for single-ply roofing membranes. Typically, roofing is exposed to the most severe environment of any major building component and, consequently, the roof usually requires a considerable amount of maintenance and repair. Because many of the newer single-ply materials have had limited service histories, maintenance and repair techniques for these materials have not been adequately developed. Maintenance and repair techniques suitable for bituminous built-up membranes may not be applicable to single-ply membranes, and different techniques may be needed for various types of single-ply membranes.

With millions of square feet of these materials being applied each year, already applied, or to be applied, a great need exists to develop measurement techniques for problem identification as well as for guidelines covering the maintenance and repair of roofs. A technological basis needs to be developed to insure that corrective measures perform as intended and do not cause additional problems. Techniques also need to be developed for evaluating proposed and existing maintenance and repair methods.

Recommended Approach:

- Analyze diagnostic procedures including NDE techniques used for conventional roofing to determine whether they apply to single-ply membranes, and develop the technical basis for the selection, use, and interpretation of NDE methods for the inspection single-ply membranes.

- Develop improved NDE methodologies, if needed, for evaluating the condition of single-ply membranes.

- Develop measurement techniques to evaluate the effectiveness of methods for repairing membrane problems such as splits, tears, and punctures.

- Develop NDE techniques to determine the quality of seams in single-ply membranes.

- Develop the technical basis for guidelines covering the maintenance and repair of single-ply membranes.

5.4.2 Objective 2--Condition of Built-Up Roofing Systems

Objective: To develop the technical basis for guidelines for non-destructive evaluations of the condition of weathered in-place built-up roofing membranes and systems and for making repairs.

Comments: Each year in the United States about 1.5×10^9 ft^2 (0.14×10^9 m^2) of low-sloped roofing are replaced or recovered. Since these are generally older roofs, it may be assumed that most have built-up membranes. Proper and routine maintenance and repair procedures could extend the life of a significant number of these roofs for many years with significant savings. In some cases, the old roofing may be replaced needlessly. In others, old roofing is left in place when it should have been removed. It is often covered with a new membrane which may fail prematurely because of inherent deficiencies in the old roofing. The building owner, faced by major decisions with large economic consequences, has little information on which the decision may be based. Even an expert must often make decisions on the basis of assumptions which are questionable.

There is a need to analyze existing data to determine the effectiveness of conventional repair techniques. Where warranted, new data and methods should be developed to assist the decision maker in deciding what procedures should be followed to extend the life of the roofing system.

Recommended Approach:

- Analyze the effectiveness of diagnostic procedures which are currently used to ascertain the condition of weathered built-up roof membranes and systems. These procedures include those for field visual examinations, as well as those for destructive and non-destructive methods of evaluation.

- Analyze laboratory testing techniques used to evaluate weathered membranes and, if necessary, develop improved measurement techniques.

- Conduct an experimental laboratory study which simulates the conditions that occur when a weathered membrane is covered with a new membrane to examine the effectiveness of this reroofing technique.

- Investigate the feasibility of using destructive and non-destructive techniques for the evaluation of weathered membranes under simulated and in-service conditions.

- Develop the technical basis for reliably predicting the remaining service life of bituminous membranes.

- Develop test methods for evaluating the performance of repair techniques and materials.

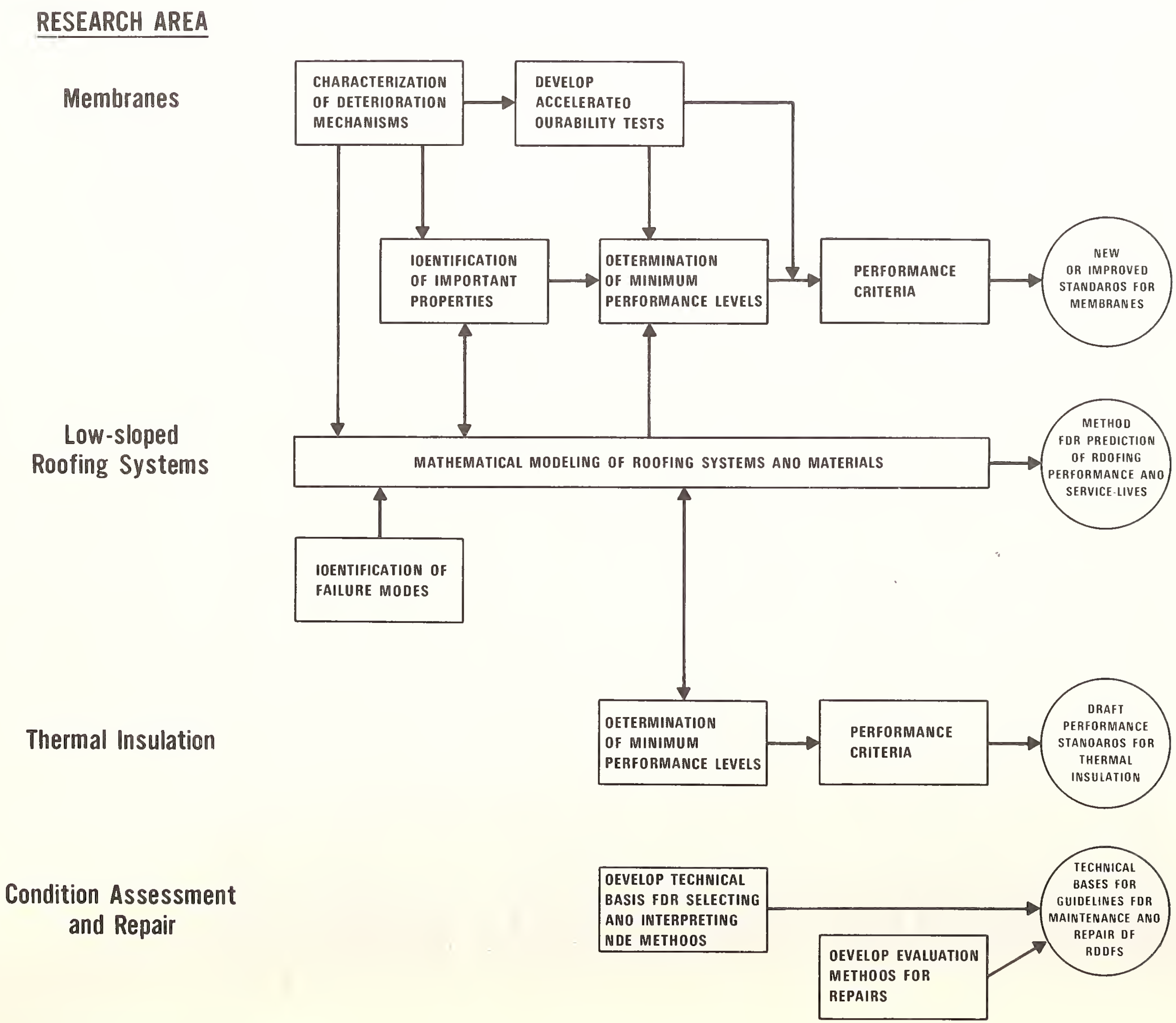
6. RESEARCH SCHEME AND CONCLUDING REMARKS

This report presents a research plan for low-sloped roofing materials and systems. The proposed research is divided into four major areas: low-sloped roofing systems, roofing membranes (single-ply and bituminous built-up), thermal insulation for roofing systems, and condition assessment and repair of roofs. The intent of the plan is to establish the technical bases for developing standards and performance levels which may assist in the selection of cost-effective and durable roofing materials and systems. The plan is broad and many years may be needed to achieve the goals and objectives proposed, even with collaboration among all segments of the roofing community. Figure 2 outlines a possible flow scheme for conducting of the proposed research, and shows the relations between proposed major activities and goals for the four major research areas. The time frame for the accomplishment of the goals and objectives will, of course, be dependent upon the available resources including personnel, funds, and facilities including equipment.

As evident from figure 2, research on low-sloped roofing systems and membranes including both single-ply and built-up bituminous is given highest priority. There is a co-dependence of the research activities in these two areas. For example, the development of models can facilitate in the development of standards for membranes because modeling provides means for identifying important membrane performance properties and determining minimum levels of performance. Values of materials properties of well-characterized membranes are needed for performing modeling computations. In addition, to have credibility, models must be validated by comparing theoretical or predicted results with experimental data. The research on low-sloped roofing systems and membranes would be expected to extend a number of years, culminating in the development of a technical basis for making realistic predictions of the performance and service lives of roofing materials and systems.

Research on thermal insulations is planned to begin later than that for roofing systems and membranes. It is believed that, unless sufficient resources were available, the magnitude of the proposed research in the plan will not allow an earlier starting time for the thermal insulation research. Nevertheless, as indicated in figure 2, values of some material properties of thermal insulations will need to be determined for the development of mathematical models on roofing systems. Research on condition assessment and repair is also planned to begin later than that for roofing systems and membranes. This research is not strongly linked with the other activities and could be started earlier if resources were available.

Figure 2 PROPOSED SEQUENCE OF MAJOR ROOFING ACTIVITIES AND GOALS



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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report presents a long-range plan for roofing research. The plan was developed in response to a need for roofing research addressing major materials problems and changes in low-sloped roofing materials technology. The intent of the plan is to establish the technical basis for developing standards and minimum levels of performance to assist in the selection of cost-effective and durable roofing materials. Four major areas of needed research are identified: (1) low-sloped roofing systems, (2) roofing membranes including single-ply and built-up, (3) thermal insulation for roofing systems, and (4) condition assessment and repair of roofs. Within each research area, a goal is given as well as a number of objectives to achieve the goal. A recommended approach to accomplish each objective is also given.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Low-sloped roofing; mathematical modeling; membranes; repair; research plan; roofs; standards; thermal insulations.

13. AVAILABILITY

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