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Thermal Insulation Research Plan for the Energy Conversion and Utilization Technologies (ECUT) Materials Program

H. A. Fine

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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METALS AND CERAMICS DIVISION

THERMAL INSULATION RESEARCH PLAN FOR THE ENERGY CONVERSION AND UTILIZATION TECHNOLOGIES (ECUT) MATERIALS PROGRAM

H. A. Fine

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NOTICE: This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

Prepared for the Assistant Secretary for
Conservation and Renewable Energy,
Office of Energy Utilization Research,
Energy Conversion and Utilization Technologies (ECUT) Program

Prepared by the
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for the
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CONTENTS

FOREWORD

This report documents both the process and the output of the process of establishing a peer review panel primarily from the private sector to suggest research and development activities appropriate for government sponsorship through the U.S. Department of Energy (DOE) Energy Conversion and Utilization Technologies (ECUT) Program on the subject of thermal insulation. We expect to use information and guidance from the document during the federal budgetary process to allow more informed decision making. All related results of that budgetary decision making will affect what the DOE or Oak Ridge National Laboratory (ORNL) can and will sponsor during this or subsequent years through detailed decisions of DOE and ORNL program managers. We wish to commend all those who participated in preparation of this plan, expecially the panel members and H. Alan Fine of the University of Kentucky.

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THERMAL INSULATION RESEARCH PLAN
FOR THE ENERGY CONVERSION AND UTILIZATION
TECHNOLOGIES (ECUT) MATERIALS PROGRAM*

H. A. Fine†

1. INTRODUCTION

1.1 THE ECUT MATERIALS PROGRAM

The U.S. Department of Energy (DOE) established the Energy Conversion and Utilization Technologies (ECUT) Program in FY 1980 with the mission to conduct generic, long-term, high-risk applied research and exploratory development in areas pertaining to energy conservation in energy conversion and utilization. Within the DOE conservation effort, ECUT serves as the applied research and exploratory development bridge between any basic research efforts in conservation conducted by the Office of Energy Research (OER) and the technology and engineering development in energy conversion and utilization funded by the Office of Buildings and Community Systems, the Office of Transportation Systems, and the Office of Industrial Programs. In areas where OER has little or no ongoing relevant basic energy research, ECUT will consider filling those gaps in research activities also. The two major goals of the ECUT Program are:

1. to evaluate new concepts for improved efficiency or alternative fuel use in energy conversion and utilization, and
2. to expand the technology base necessary for development of improvements in energy conversion and utilization.

ECUT is primarily intended to support applied research and exploratory development on a specific concept or idea at the laboratory or bench scale to bring it to a state where it might be carried into more advanced technology and engineering development funded by private industry or other

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government programs. The program supports work in private industry, academia, and government. Typical contracts are in the range from $50,000 to $200,000 per year for one to three years.

The ECUT Program currently has four major subprograms: materials, catalysis and biocatalysis, combustion and thermal sciences, and tribology. The mission of the ECUT Materials Program is to support the goals of the ECUT Program in the materials area. The major ECUT Materials goals are:

1. to identify base-technology applied research and exploratory development needed to overcome materials limitations for advanced energy-conserving processes, devices, or concepts in energy conversion and utilization; and
2. to conduct applied research and exploratory development sufficient to indicate whether or not those limitations can be overcome.

ECUT Materials is funded at approximately $5 million per year. Current thrusts include exploration of innovative concepts in high-temperature materials for energy-conserving devices and processes such as advanced heat engines and high-temperature heat exchangers, lightweight materials in energy conservation, and materials by design. A fourth area, thermal insulation materials, may be added in FY 1986 and is the focus of this report.

1.2 THE INSULATION PLANNING EFFORT

The purpose of this planning effort was identification of the proper role for ECUT in the area of thermal insulation. Because of the extreme breadth of the insulation field, a panel of experts was assembled to aid in this task. Panel members with a wide diversity of expertise in the areas of property measurement, research, manufacturing and use of insulation in residential and commercial buildings and appliances, and industrial applications were selected. The panel worked under the direction of H. Alan Fine, and it was asked to review the state of the art in thermal insulations and suggest a research plan for this addition to the ECUT Materials Program.

The panel met for the first time in Ft. Mitchell, Kentucky, on April 11 and 12, 1985. The members of the panel for the first meeting are given in Appendix A. The product of the first meeting was a list of 46 one-sentence task descriptions and 18 detailed task descriptions that the panel believed warranted further consideration for inclusion in the research plan.

Following the first meeting, the tasks were combined into a draft integrated plan by H. Alan Fine. This draft included classification of the tasks into three categories: material considerations involving the atomistic and molecular processes, i.e., all characteristics of insulation which are not dependent on the size of the insulation sample; component considerations involving processes affected by the size of the insulation and its boundaries; and system considerations. Each of the three categories was further subdivided into models, development, and measurement technology. The draft integrated plan was distributed to the panel for review in late June 1985.

Prior to the second panel meeting, a condensation of the categorized list of tasks was developed by H. Alan Fine. This condensation eliminated duplicates and combined some of the one-sentence task descriptions with the more detailed task descriptions. The revised list was given to the panel at the beginning of the second panel meeting.

The second panel meeting was held July 8 and 9, 1985, in Washington, D.C. The members of this panel are given in Appendix B. Preliminary discussions resulted in the elimination of many of the tasks from further consideration, either because they were being done by another organization, not within the ECUT mission, or were of very low priority. Fourteen tasks remained. These were then graded and prioritized based on the following system:

1. the technical merit of the task (zero to 30 points),
2. the importance of the task to national needs (zero to ten),
3. the potential energy savings resulting from a successful completion of the task (zero to ten),
4. the reasonableness of the cost of the task compared with the benefits which may result (zero to ten),
5. the role for the government in performing the task (zero to ten), and
6. the fit between the task and the ECUT mission (zero to 30).

The list was further reduced by combining the two highest priority tasks, energy transfer models and moisture and mass transfer models, into one task involving all modeling efforts. The prioritized list of tasks is given in Appendix C.

The plan which follows was based upon the prioritized list of tasks, the task descriptions, and the discussions on the second day of the second panel meeting.

2. OBJECTIVES

The primary objective of an ECUT-funded research program on thermal insulation is to model, understand, measure, and improve materials important to energy-conserving actions and energy-production devices and to develop the base technologies required to attain an "insulation by design" capability. This effort will consist of a continuing planning and assessment subtask to guide a parallel subtask on the needed base technology. Elements in the planning subtask will include economic analyses, technology need reviews, and state-of-the-art assessments on selected insulation concepts and for insulation in general. The base technology program will include: information exchange from existing federally funded and foreign sources; development and validation of mechanistic models for energy, moisture, and mass transfer phenomena acting in and controlling the characteristics of thermal insulations; investigation of creative new ways to determine the properties required to validate the transport models; and the materials research to demonstrate improvements predicted by the mechanistic models and to establish insulation by design strategies. Brief descriptions of the objectives of each of the subtasks follow.

2.1 INSULATION PLANNING

The base technology research activities will be guided by the planning subtask. The planning effort includes:

A. Economic Analyses – Identify the areas with the potential for greatest market penetration and energy conservation.

B. Technology Need Reviews — Review and update the ECUT research plan commensurate with current technological levels and national needs by periodically convening an insulation topical panel.

C. Assessments of Selected Insulation Concepts — Review and evaluate particular insulation concepts as part of the planning function.

2.2 BASE TECHNOLOGY

Specific objectives to develop the base technologies required to obtain the insulation by design capability are described below.

A. Information Transfer — Review available published and catalogued literature for specialized technical information generated by the aerospace industry, other federally funded programs, and foreign sources. Determine if technology transfer and information exchange should happen and, if so, cause it to happen through established procedures such as preparation of new technical abstracts and identification of key words. Particular emphasis should be on:

1. energy, moisture, and mass transfer models;
2. measurement technology; and
3. materials research.

B. Models for Transport Phenomena — The goals of the modeling effort will include:

1. review of the analytical models and procedures that have been developed for heat, moisture, and mass transfer in discontinuous media;
2. critical evaluation of the existing models by analyses and comparison with experimental data;
3. document the models which are valid and their application to insulation research; and
4. recommend new or revised models and experimental techniques and materials tests to provide scientific verifications.

C. Measurement Technology — Develop measurement techniques for quantification of various properties affecting the performance of insulations. Areas to include should be:

1. structural characteristics such as the particle, fiber, or cell size distribution;

2. optical properties;
3. moisture measurement and determination of the fraction of free and adsorbed moisture;
4. safety and combustion characteristics; and
5. stability and degradation, i.e., corrosion properties.

D. Materials Research - Using the ECUT "Materials by Design" approach and the models developed in (B):

1. Establish the goals to form the basis for the materials research. The goals will then establish the phenomenological approaches to be taken and the materials science required to accomplish the improvements at the atomic and microscopic levels, where applicable. Factors to be considered shall include:
   a. heat transfer by radiation, conduction, and convection;
   b. moisture and mass transfer;
   c. long-term stability (chemical, mechanical, and physical properties);
   d. geometry of constituents as related to density, radiative and conductive transport, mass transfer, strength, and environmental degradation;
   e. intrinsic thermophysical and optical properties; and
   f. combinations of materials to reduce thermal energy transport, environmental degradation, and cost or to improve safety, strength, and productibility.

2. Conduct the materials research required to improve the properties of insulation components. Initial areas of investigation would be optimization of optical properties to reduce radiative transport, minimization of effects of interstitial gas present in nonevacuated insulations, reduction of effects of condensible gases and diffusion processes, and prevention of packing or migration of constitutents with time (vibration, mechanical loading, etc.). Additional areas to investigate include:
   a. make greater use of particle shape orientation techniques to optimize mechanical and thermal properties; and

b. investigate the feasibility of using additives in current insulation materials in order to improve their effectiveness especially at elevated temperatures.

3. OBJECTIVE STRATEGIES

A variety of thermal insulations are used in conventional and advanced energy-conserving and energy-producing systems. A realistic research program must build on the existing knowledge base and must design new materials that have potential for additional energy conservation.

3.1 INSULATION PLANNING

The ECUT thermal insulation effort is designed to undertake high-risk, long-term, generic research of a more basic nature than the existing federally funded mission-oriented programs. Thus a continuous planning effort is needed to focus the base technology research on knowledge needed to achieve insulations by design. The components of this planning effort include:

A. Economic Analyses - A small continuing effort to identify areas with large potential for market penetration and energy savings resulting from the development of a new insulation concept,

B. Technology Need Reviews - Biannual thermal insulation panel meetings to review and modify, if needed, the ECUT research plan for thermal insulations, and

C. Assessments of Specific Insulation Concepts - Short state-of-the-art assessments for specific insulation concepts that review existing property and performance data and outline needed research.

3.2 BASE TECHNOLOGY

The base technology subtask will include the four research projects described below.

A. Information Transfer - Thermal insulation-related technology developed and documented in past R&D programs in aerospace and other federally funded programs, and by the international community, has not been readily available to the public sector, even with supportive dissemination policies for nonconfidential materials. Narrowly focused research programs directed to solve specific project problems have not found the expected broader utility and application in the development of new thermal insulation materials and systems. The specialized technical information will be located through personal contacts with researchers in these other fields and by using such facilities as the Lawrence Berkeley Laboratory (LBL) search capabilities. New keywords and abstracts will be written which restate the objectives to highlight the potential of the information for wider application.

B. Models for Transport Phenomena - Many analytical models exist for understanding the transport processes which occur within thermal insulation. However, they are often incorrectly applied, and some are invalid except for very select boundary conditions. Others are empirical relationships which have been tested only over a very limited set of conditions, and some are fundamentally in error. Finally, the degree to which the models have been verified by careful experiment or exact analyses is poor in many cases.

The initial step to advance the state of technology in the science of thermal insulation is the critical review of the mechanistic models which are applicable to the understanding and prediction of the performance of materials as related to heat, moisture, and mass transfer processes in discontinuous media and the safety and stability of these materials in the applications environment. The next step is to develop analytical models which fill the voids of the current state of technology in the understanding of the applicable mechanisms. The final steps are to prepare a compendium of analytical techniques and then assess the improvements which might be achieved through materials research and development. As the state of the art is further advanced for energy transfer, the program will initially focus on this subject with moisture and mass transfer to follow. Safety and stability modeling efforts will begin after energy transfer is completed and moisture and mass transfer are well under way.

C. Measurement Technology - Heat transfer processes in insulations are very complex. Attempts to develop and validate equations to predict the performance of an insulation are difficult when many of the significant variables remain unquantified. Much work has been done to relate the performance of insulations to variables assumed to govern the heat flow process. Models have shown, however, that other properties, which are as yet unquantified, may be as important as those which have been measured. The lack of moisture transfer models may be traced to the difficulties in measuring the localized moisture content and fractions of adsorbed and free moisture.

Properties which remain unknown for many insulations include the structural characteristics such as the particle or fiber size distribution, the optical/radiation-heat-transfer properties, and the combustion, stability, and corrosion characteristics. Development of new measurement technologies will be directed by the needs of the modeling effort to provide the information necessary to validate the models and attain the insulation by design capability.

D. Materials Research – The overall performance of thermal insulations may be significantly improved through the development of analytic techniques which accurately model the key performance factors of foam, particulate, and fibrous insulations. These factors include intrinsic properties, heat and mass transfer mechanisms, mechanisms for moisture transfer and condensation, strength, safety (combustion), and stability or durability (corrosion) in the environments in which they are used. Using the models developed in (B), the limits of performance enhancement that are physically achievable will be defined. These limits will serve as a guide to research in the areas of materials modification, new materials development, new combinations of existing or advanced materials, and measurement technology development. Specific material improvements suggested by the modeling efforts that are physically possible in thermal insulations so that their value, from both economic and energy conservation criteria, may be improved will then be tested. The feasibility of the insulation by design concept will be established.

4. ACCOMPLISHMENTS

4.1 PRIOR YEARS THROUGH FY 1985

4.1.1 Insulation Planning

During FY 1985, the ECUT Materials Program supported three thermal insulation-related efforts: (1) an assessment of evacuated microsphere insulation-related efforts: (1) an assessment of evacuated microsphere systems as thermal insulations; (2) an analysis of potential energy savings that would result from increased thermal insulation usage; and (3) an assessment of the role for the ECUT Materials Program in the thermal insulation field (this document).

The evacuated microsphere study examined the ability of thin-walled glass microspheres which enclose evacuated interiors to achieve high thermal resistances. This could overcome the objection to evacuated panels where a single puncture can be devastating. Potential energy savings were estimated for residential and commercial buildings and appliances, as well as industrial uses. The ECUT role assessment convened two panels of experts with a wide spectrum of viewpoints on the research, manufacturing, and user requirements for thermal insulations. The output of this effort was a prioritized list of research needs appropriate to the ECUT mission. (See Appendix C.)

4.1.2 Base Technology

In FY 1982 and FY 1983, the ECUT Materials Program supported a study at Massachusetts Institute of Technology (MIT) to formulate a fundamental model of foam insulation R values and aging. Their work with radiant heat transfer mechanisms has identified cell wall opacification/increased extinction coefficient as a potential route to increased insulation value in as-manufactured foams. Their research into gas permeability mechanisms has indicated that the most important parameters for predicting aging in foam insulation are polymer distribution, polymer permeability, and foam density.

Beginning in FY 1984, the MIT work was supported by the DOE Office of Building and Community Systems, which has supported building materials research at Oak Ridge National Laboratory (ORNL) and other facilities to produce technical data, test procedures, guidelines, and standards needed by the building community to produce energy efficient buildings.

4.2 PROJECTED FOR FY 1986, FY 1987, AND FY 1988

4.2.1 Insulation Planning

An effort of approximately two-thirds of a man-year will continue throughout this period. Expected accomplishments are as follows:

A. Economic Analyses - A report outlining the energy conservation potential through improved or increased insulation usage should be available in mid FY 1986. This effort will continue at approximately a one-third man-year level until the end of FY 1986, with a report due by mid FY 1987. The analysis effort will resume in mid FY 1988 at the one-third man-year level with a report due by mid FY 1989.

B. Technology Needs Reviews - The topical panel on thermal insulation will be reconvened in the second half of FY 1987 to review the ECUT research plan. A revised plan will be developed by the end of FY 1987. This effort will comprise approximately a one-third man-year effort.

C. Assessments of Selected Insulation Concepts - An approximately one-third man-year effort will be undertaken during each of the three years. The initial concepts to be examined include ceramics for heat engine insulation and the need for property information for low-density intermetallics. Other concepts worthy of study are described in Appendix C. Each assessment is expected to take six months and result in a report. One assessment will be done each year.

4.2.2 Base Technology

The projected accomplishments of this task are as follows.

A. Information Transfer - This project will begin in FY 1986 at the one man-year level. By the end of the year, the literature review should be completed. A report containing the rewritten abstract and new keywords should be ready in mid FY 1987.

B. Models for Transport Phenomena - This effort will begin in FY 1987 at the four man-year level. Initially, the effort will consist of a three man-year effort on energy transfer and a one man-year effort on mass and moisture transfer. By mid FY 1988, the energy transfer effort should begin to come to a close with reports being generated. A switch in emphasis toward moisture and mass transfer will then occur. In FY 1988 both programs should be at the two man-year level.

C. Measurement Technology - This effort will begin in FY 1987 at the one man-year level and continue at this level through FY 1988. The development of a new measurement technique will take approximately one year with a report being written at the conclusion of the development work on each technique.

D. Materials Research - This project will begin in mid FY 1988 and will be based upon inputs from the modeling task. During the initial six-month period, objectives for the remainder of the program will be established and a report issued.

4.3 PROJECTED FOR FY 1989 THROUGH FY 1993

4.3.1 Insulation Planning

A. Economic Analyses - A project will continue on an alternating-years basis to establish the effect of any economic or technological changes on the potential for energy conservation and market penetration capability of new insulation concepts.

B. Technology Need Reviews - The insulation topical panel will convene biannually to revise the ECUT research plan in keeping with the current technological needs and economic considerations.

C. Assessments of Selected Insulation Concepts - Approximately one state-of-the-art assessment will be developed each year.

4.3.2 Base Technology

In this time period, the base technology program will consist of three projects: modeling, measurement technology, and materials research. During FY 1989, the energy transfer modeling effort should be completed. The modeling effort will continue through 1991, however, with emphasis on moisture and mass transfer. The modeling efforts will establish which techniques to develop in the measurement technology effort. The measurement technology project will continue through FY 1990 with the development of two more measurement techniques. Materials research will continue throughout the period and establish the feasibility of insulation improvements as set forth by the models, and the insulation by design capability.

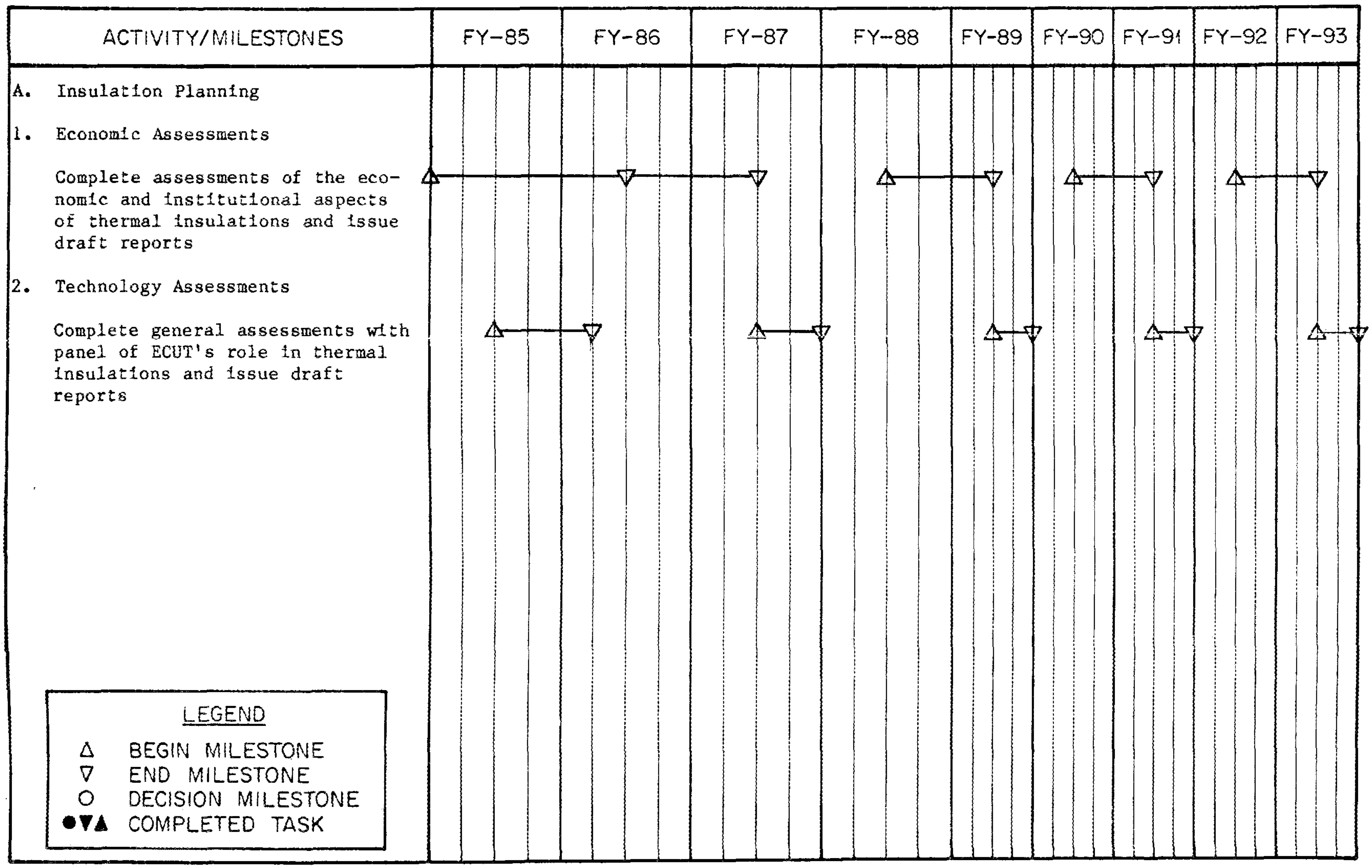
5. SCHEDULE AND MILESTONES, FY 1985 THROUGH FY 1993

The schedule of activities and the milestones for the project, FY 1985 through FY 1993, are shown in Fig. 1 on the following pages.

SCHEDULE AND MILESTONES, FY 1985 – 1993

Fig. 1

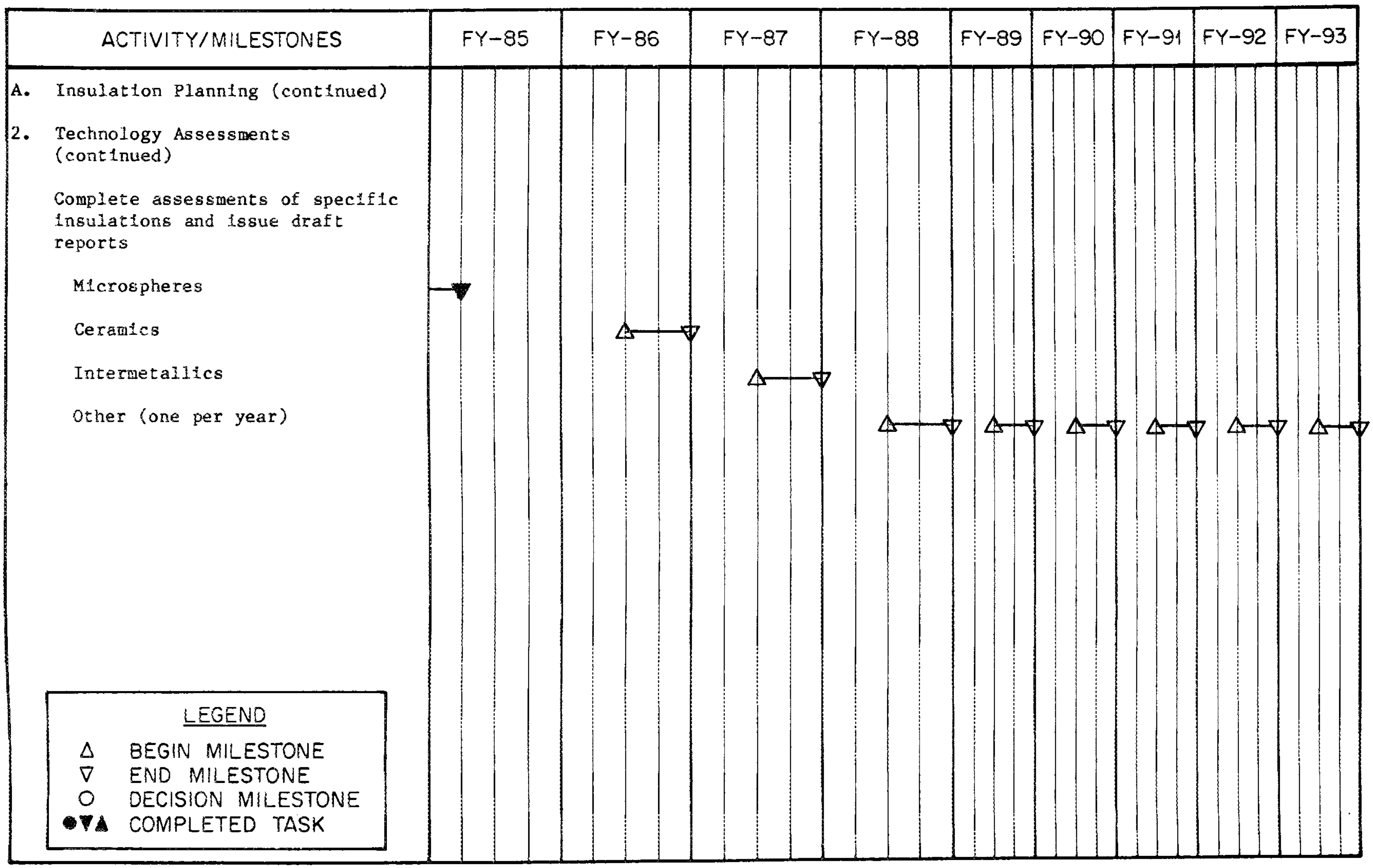
INSULATING MATERIALS



SCHEDULE AND MILESTONES, FY 1985 – 1993

Fig. 1 (continued)

INSULATING MATERIALS



SCHEDULE AND MILESTONES, FY 1985 – 1993

Fig. 1 (continued)

INSULATING MATERIALS

ACTIVITY/MILESTONES	FY-85	FY-86	FY-87	FY-88	FY-89	FY-90	FY-91	FY-92	FY-93
B. Base Technology									
1. Information Transfer									
Complete efforts to transfer of various technologies to energy-related issues and issue draft reports		△ ○	▽						
2. Models for Transport Phenomena									
Complete development of models and experimental verifications to predict energy transport in insulations and issue draft reports			△	○	▽				
Complete development of models and experimental verifications to predict moisture and mass transport in insulations and issue draft reports			△	○			▽		

LEGEND

- △ BEGIN MILESTONE
- ▽ END MILESTONE
- ○ DECISION MILESTONE
- ●▼▲ COMPLETED TASK

SCHEDULE AND MILESTONES, FY 1985 – 1993

Fig. 1 (continued)

INSULATING MATERIALS

ACTIVITY/MILESTONES	FY-85	FY-86	FY-87	FY-88	FY-89	FY-90	FY-91	FY-92	FY-93
B. Base Technology (continued)									
3. Measurement Technology									
Complete development of advanced measurement technologies for insulations and issue draft reports			△	○		▽			
4. Materials Research									
Complete materials research to advance the state-of-the-art in the base technologies of insulations and issue draft reports				△					▽

LEGEND

- △ BEGIN MILESTONE
- ▽ END MILESTONE
- ○ DECISION MILESTONE
- ●▼▲ COMPLETED TASK

6. PROJECT BUDGET PLANNING AND PROGRAMMING, FY 1986 THROUGH FY 1993

Budget planning and programming for the project, FY 1986 through FY 1993, are shown in Table 1 on the following pages.

Table 1
PROJECT BUDGET PLANNING AND PROGRAMMING

FY 86-93 ($ 000) - OPERATING

PROJECT TITLE: ECUT Materials — WORK ELEMENT: Insulating Materials

TASK	ACTUAL FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93
A. Insulation Planning									
1. Economic Assessments									
Complete assessments of the economic and institutional aspects of thermal insulations and issue draft reports.	(~20)	40		50					
	(Assessment work done in FY 85 under Project Direction)								
2. Technology Assessments									
Complete general assessments with panel of ECUT's role in thermal insulations and issue draft reports.			50		50				
TOTAL									

PAGE 1 OF 5

Table 1 (continued)
PROJECT BUDGET PLANNING AND PROGRAMMING

FY 86-93 ($ 000) - OPERATING

PROJECT TITLE: ECUT Materials — WORK ELEMENT: Insulating Materials

TASK	ACTUAL FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93
A. Insulation Planning (continued)									
2. Technology Assessments (continued)									
Complete assessments of specific insulations and issue draft reports.									
Microspheres	(40-FY 83)								
Ceramics		60							
Intermetallics			50						
Other (one per year)				50	50	50	50	50	50
SUBTOTAL	(40)	100	100	100	100	100	100	100	100

Table 1 (continued)
PROJECT BUDGET PLANNING AND PROGRAMMING

FY 86-93 ($ 000) - OPERATING

PROJECT TITLE: ECUT Materials   WORK ELEMENT: Insulating Materials

TASK	ACTUAL FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93
B. Base Technology									
1. Information Transfer									
Complete efforts to transfer various technologies to energy-related issues and issue draft reports.		150	75						
2. Models for Transport Phenomena									
Complete development of models and experimental verifications to predict energy transport in insulations and issue draft reports.			450	300	300				
Complete development of models and experimental verifications to predict moisture and mass transport in insulations and issue draft reports.			150	300	300	TBD	TBD		
TOTAL									

PAGE 3 OF 5

Table 1 (continued)
PROJECT BUDGET PLANNING AND PROGRAMMING

FY 86-93 ($ 000) - OPERATING

PROJECT TITLE: ECUT Materials — WORK ELEMENT: Insulating Materials

TASK	ACTUAL FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93
B. Base Technology (continued)									
3. Measurement Technology									
Complete development of advanced measurement technologies for insulations and issue draft reports.			150	150	150	TBD			
4. Materials Research									
Complete materials research to advance the state-of-the-art in the base technologies of insulations and issue draft reports.				150	300	TBD	TBD	TBD	TBD
SUBTOTAL		150	825	900	1050	TBD	TBD	TBD	TBD

PAGE 4 OF 5

Table 1 (continued)
PROJECT BUDGET PLANNING AND PROGRAMMING

FY 86-93 ($ 000) - OPERATING

PROJECT TITLE: ECUT Materials WORK ELEMENT: Insulating Materials - Summary

TASK	ACTUAL FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93
A. Insulation Planning	(40)	100	100	100	100	100	100	100	100
B. Base Technology		150	825	900	1050	TBD	TBD	TBD	TBD
TOTAL	(40)	250	925	1000	1150	100+	100+	100+	100+

PAGE 5 OF 5

Appendix A

ATTENDEES AT THE FIRST PANEL MEETING ON APRIL 11 AND 12, 1985, IN FT. MITCHELL, KENTUCKY

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Appendix B

ATTENDEES AT THE SECOND PANEL MEETING ON JULY 8 AND 9, 1985, IN WASHINGTON, D.C.

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Appendix C

PRIORITIZED LIST OF ONE-SENTENCE AND DETAILED TASK DESCRIPTIONS DEVELOPED AT THE SECOND PANEL MEETING ON JULY 8 AND 9, 1985, IN WASHINGTON, D.C.

PRIORITIZED LIST OF TASK DESCRIPTIONS

Very High Priority

1.* Mechanistic models of heat, moisture, and mass transfer.

2.* Measurement technology for property characterization.

High Priority

3.* Technology transfer and information exchange.

4.* Heat transfer models for data analysis.

Average Priority

5.* New insulation concepts.

6.* High resistance panels for components.

7.* Thermal and moisture standard reference materials.

8.* High temperature round robin.

9.* Property data base at other than ambient temperature.

Low Priority

10.* Predictive evaluation system models.

11. Develop performance criteria and identify key physical property boundaries which now "bottleneck" progress in engineering better performing thermal insulation systems as a start towards providing new problem-solving options.

Very Low Priority

12. Write a monograph which summarizes the basic mechanism of heat transfer in insulation with emphasis on the physical mechanisms (without extensive mathematical details of analysis) and verification data as available. Separate sections on fibrous, powder, reflecting layers, and foam insulation should be included.

13.* Composite materials.

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*Asterisks indicate that a detailed description is included in this Appendix.

TOPIC 1: MECHANISTIC MODELS FOR INSULATION DEVELOPMENT

BACKGROUND: The overall performance of thermal insulations may be significantly improved through the development of analytic techniques which accurately model the key performance factors of foam, particulate, and fibrous insulations. These factors include intrinsic properties, heat and mass transfer mechanisms, mechanisms for moisture transfer and condensation, strength, safety (combustion), and stability or durability (corrosion) in the environments in which they are used. The models will first define the limits of performance enhancement that are physically achievable. They will then serve as a guide to research in the areas of materials modification, new materials development, new combinations of existing or advanced materials, and measurement technology development.

Many analytical models exist for understanding the interactions associated with atomic and microscopic processes which occur within thermal insulation. However, they are often incorrectly applied, and some are invalid, except for very select boundary conditions. Others are empirical relationships which have been tested only over very limited sets of conditions, and some are fundamentally in error. Finally, the degree to which the models have been verified by careful experiment or exact analyses is in many cases poor.

The initial step to advance the state of technology in the science of thermal insulation is the critical review of the mechanistic models which are applicable to the understanding of and the prediction of the performance of materials as related to heat, moisture, and mass transfer processes in discontinuous media and the safety and stability of these materials in the applications environment. The next step is to develop analytical models which fill the voids of the current state of technology in the understanding of the applicable mechanisms. The final steps are to prepare a compendium of analytical techniques and then assess the improvements which might be achieved through materials research and development.

STATUS: Numerous models of varying degrees of sophistication and accuracy have been developed over the past half-century. In general, they have not been verified to make them broadly applicable, nor are they able to provide the understanding of the effects of intrinsic materials properties on insulation performance. This lack of a firm understanding of the mechanisms precludes the establishment of a long term materials research plan to accomplish the further conservation of energy by design.

OBJECTIVES: The overall objective of this multi-year, multi-task project is to firmly establish the technology required to assess the improvements that are physically possible in thermal insulations so that their value, from both economic and energy conservation criteria, may be optimized and to provide the direction for the materials research which will be required to accomplish these improvements. The specific objectives are:

(1) Conduct a review of the analytical models and procedures that have been developed for heat, moisture, and mass transfer in discontinuous media.

(2) Critically evaluate the existing models by analyses and comparison with experimental data.

(3) Document the models which are valid and their application to insulation research.

(4) Recommend new or revised models and experimental techniques and materials tests to provide scientific verifications.

(5) Using the ECUT "Materials by Design" approach and the models developed in tasks (1) through (4), establish the goals to form the basis for the materials research plan. This plan shall establish the phenomenological approaches to be taken and the materials science required to accomplish the improvements at the microscopic and the atomic levels, where applicable. Factors to be considered shall include:

a. heat transfer by radiation, conduction, and mass transfer;

b. moisture and mass transfer;

c. long-term stability (chemical, mechanical and physical properties);

d. geometry of constituents as related to density, radiative and conductive transport, mass transfer, strength, and environmental degradation;

e. intrinsic thermophysical and optical properties; and

f. combinations of materials to reduce thermal energy transport, environmental degradation, and cost or to improve safety, strength, and producibility.

(6) Conduct the materials research required to improve the properties of insulation components. Initial areas of investigation would be optimization of optical properties to reduce radiative transport, minimization of effects of:

a. make greater use of particle shape orientation techniques to optimize mechanical strengths as in flexure and thermal energy management broad area of materials/properties investigation; and

b. investigate the feasibility of using additives in current insulation materials in order to improve their effectiveness especially at elevated temperatures.

VENDOR: The Oak Ridge National Laboratory should be the lead organization to direct and coordinate a multi-disciplinary team effort. Four or more members from leading university or industrial organizations should make up the team. A topical panel should also be formed to annually review the direction of the effort.

SCHEDULE: During the initial year, efforts will focus on heat transfer as this field has been the subject of a great deal of interest in the past decade. In ensuing years, effort will switch from heat transfer to moisture and mass transfer mechanisms.

BUDGET: Four man-years per year.

TOPIC 2: MEASUREMENT TECHNOLOGY FOR PROPERTY CHARACTERIZATION OF THERMAL INSULATION

BACKGROUND: The transfer processes which occur in insulations are very complex. Attempts to develop and validate equations to predict the performance of an insulation are difficult when many of the significant variables remain unquantified. Two of these are the particle or fiber size distribution and the structural characteristics. Other properties which remain unknown for many insulations are the optical/radiation-heat-transfer properties, combustion, stability, and corrosion characteristics.

Much work has been done to relate the performance of insulations to variables which are assumed to govern the heat flow process. Models have shown, however, that other properties, which are as yet unquantified, may be as important as those which have been measured. The lack of moisture transfer models may be traced to the difficulties in measuring the localized moisture content and fractions of adsorbed and free moisture.

STATUS: Recent work relating to the ASTM C-16.30/MIMA round robin requiring the development of a representative equation has brought forth the need to investigate the possibility of creating new ways to evaluate some of the physical characteristics which affect the thermal properties of the insulation. The two variables which need means of quantification are:

(1) evaluation of fiber or particle diameter distributions and relating the mean diameter and a nominal value describing the distribution to the optical properties and thermal performance; and

(2) evaluation of the structural characteristics of the solid matrix and relating these variables to the thermal performance.

Model development to help understand the mechanisms that control moisture and mass transfer within insulations will require the development of specialized measurement techniques, such as for the determination of the localized moisture content and the fractions of free and adsorbed moisture. Development of models for safety related problems, such as combustion, and stability and degradation, i.e., corrosion, will also produce the need for new measurement techniques and procedures.

OBJECTIVES: Develop measurement techniques for quantification of various properties affecting the performance of insulations. Areas to include should be:

(1) structural characteristics such as the particle, fiber, or cell size distribution;
(2) optical properties;
(3) moisture measurement and determination of the fraction of free and adsorbed moisture;
(4) safety and combustion characteristics; and
(5) stability and degradation, i.e., corrosion, properties.

SCHEDULE: 1 man-year per task or technique.

BUDGET: $150,000 per task or technique.

TOPIC 3: TECHNOLOGY TRANSFER AND INFORMATION EXCHANGE

BACKGROUND: Thermal insulation-related technology developed and documented in past R&D programs in aerospace, for example, has not been readily available to the public sector even with supportive dissemination policies for nonconfidential material. Narrowly focused research programs directed to solve specific project problems have not found the expected broader utility and application in the development of new thermal insulation materials and systems. Identifying this specialized technical information using such facilities as the LBL search capabilities and restating objectives to highlight its potential for wider applicability remain to be implemented.

STATUS: Aerospace and other federally funded organizations appear unable to implement such information exchange; current abstracts and key words in technical indexes provide only limited and specialized accessibility.

OBJECTIVE: Review available published and classified information for specialized technical information generated by the aerospace industry to confirm the feasibility and benefits of developing new technical abstracts and key words. Review other federally funded and foreign sources of specialized technical information (for example, patent literature) to determine if technology transfer and information exchange enhancement is feasible and of benefit. Particular emphasis during this program should be placed on:

(a) heat and mass transfer models,
(b) testing procedures and equipment, and
(c) materials development and processing.

VENDOR: Personal contacts must be by insulation industry experienced and technically knowledgeable personnel. A team of two or more experts with varied backgrounds would enhance the chances for success.

SCHEDULE: Literature survey and personal contacts - 12 months. Report preparation - 6 months.

BUDGET: $225,000.

TOPIC 4: CRITICAL EVALUATION OF HEAT TRANSFER MODELS FOR DATA ANALYSIS

BACKGROUND: It is known that reliable prediction of insulation performance is greatly dependent on the accuracy of the available property data. Much of the data is deduced from models which interpret results, such as total heat flow, temperature difference, etc., obtained from various experimental apparatus. Some of the data-reduction models used in the literature have never been rigorously tested. For example, heat transfer by combined conduction and radiation is often treated as an independent and additive process. How results obtained from this kind of treatment compare with those that might be obtained from more exact combined mode heat transfer analyses has never been ascertained.

STATUS: Many models exist, but few have been rigorously tested for a range of variables.

OBJECTIVES:

(1) Define the limits and applicability of existing models and develop new models where needed.

(2) Quantify the range of errors in the data deduced from the models.

(3) Identify the simplest approximations and the data needed for description of heat transfer in materials and components.

VENDOR: Facility with measurement and theoretical capabilities.

SCHEDULE: 36 months.

BUDGET: $300,000 per year.

TOPIC 5: NEW INSULATION CONCEPTS

BACKGROUND: Unaged closed cell foam insulations have the highest R-value per inch of any conventional, i.e., nonvacuum, insulation available at present. The insulation has widespread application in buildings, appliances, and industry. Since foam insulation can also provide structural support as well as act as a thermal barrier it may be the insulation system of choice for numerous applications. Improvements in the value of the foam, allowing thinner insulations or higher energy efficiencies at the same thickness, would be welcomed in their applications, e.g., the ADL study of energy savings with higher efficiency refrigerators.

One-half or more of the heat transfer through foams is due to conduction through the gas within the foam cells. Removal of that gas in subvolumes of the foam, i.e., semivacuum foam, or inclusion of microparticles in the cell to reduce effective gas conductivity, would allow the effective conductivity of the foam to be reduced.

STATUS: Evacuated closed cell foams are being studied in Canada.

OBJECTIVE: Produce vacuum subvolumes within foam insulation to determine the ultimate R-value improvement which can be achieved. The best properties of non-penetrable barrier to contain the vacuum without negating the insulation improvement by providing a high conductivity path for circumferential heat flow must be established. Materials for the barrier include thin, flexible glass films. The use of fine structural insulations which have very low vapor pressures within the vacuum volume to support the pressure difference must be examined.

VENDOR: A university is needed to carry out the basic research, preferably one with the expertise in this area.

SCHEDULE: 24 months.

BUDGET: $100,000 per year.

TOPIC 6: HIGH RESISTANCE PANELS FOR COMPONENTS

BACKGROUND: Recently, both the French and Japanese have produced thermal insulation panels with R-values higher than 13 per inch. It has been speculated that the Japanese high R-value insulation will be utilized in many Japanese appliances in the near future. As a consequence, there is an urgent need for the American industry to develop and produce high R-value insulations as soon as possible.

Measurements on panels and components are essential to developing a better understanding of the heat transfer mechanisms in these systems. These components should contain a wide variety of filler materials, so that the effects of particle size and size distribution can be established. In addition, as the vacuum level in the panel is of paramount importance, measurements as a function of pressure as well as temperature are needed. Finally, since the pressure is such an important variable, a program to develop better containment materials is needed. This project will necessitate studies as a function of time to quantify aging effects due to the permeability of the panel coverings and offgassing of adhesives, filler material, and the cover itself.

STATUS: Some work is being done on high R-value insulation in this country. The activities are, however, not integrated. The U.S. government, in particular the DOE, should play a leading role in pushing for more research efforts in this area. The U.S. appliance industry could avoid a potentially significant loss of the market if it can produce appliances that are competitive with Japanese appliances that are outfitted with high R-value insulation.

OBJECTIVES: (1) Develop a knowledge base for the design of advanced insulation systems for appliances.

(2) Identify acceptable low permeable barriers for containing evacuated insulation made with the fine powders.

VENDOR: Entire insulation community and material industry.

SCHEDULE: 3 years.

BUDGET: $300,000 per year.

PERTINENT REFERENCES:

1. W. T. Lawrence and F. E. Ruccia, *Development of Advanced Insulation for Appliances. Task I Report,* ORNL/Sub-81/13800/1 (1981).

2. D. L. McElroy, D. W. Yarbrough, G. L. Copeland, F. J. Weaver, R. S. Graves, T. W. Tong, and H. A. Fine, *Development of Advanced Thermal Insulation for Appliances,* ORNL/CON-159 (1984).

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TOPIC 7: MOISTURE AND HIGH TEMPERATURE APPLICATIONS STANDARD REFERENCE MATERIALS

BACKGROUND: There has been for many years a great need for the thermal insulation community to acquire confidence in test results obtained at high temperatures (100 to 600°C). To achieve this requires a concerted effort on the part of the commercial laboratories, the insulation industry, and the referencing agency, the National Bureau of Standards (NBS).

A major program aimed at the resolution of this situation should be initiated. The work should be carried out along several concurrent paths. This would require a greater effort in time, personnel, and money for the development of several types of reference materials. At the same time a round robin should be carried out among the laboratories having the high temperature test equipment (Topic 8).

STATUS: The National Bureau of Standards in Boulder in cooperation with the Manville R&D Center is working towards the development of refractory fiber board as a standard reference material (SRM). This activity should receive more technical and financial assistance through the support of a round robin, technical community assistance, and an expanded program involving different materials.

A moisture standard reference material existed. The quantity of this material was, however, exhausted and, due to a lack of funds, a new material has not been developed.

OBJECTIVE:

(1) Intensify the efforts to develop a high temperature standard reference material.

(2) Begin work to develop other standard reference materials, e.g., a loose-fill insulation for the temperature range of 100 to 600°C for high temperature pipe/plate testers.

(3) Develop a new moisture standard reference material.

VENDOR: The National Bureau of Standards in Boulder, having the experience in high temperature measurements aimed at the development of an SRM and having gained experience with the ASTM C-16.30/MIMA Round Robin analysis and report, would be well qualified to carry out this program.

TOPIC 8: HIGH TEMPERATURE ROUND ROBIN

BACKGROUND: Recently, an extensive evaluation of the thermal insulation measurement capabilities at room temperature was completed. This evaluation was essentially at a single temperature of 23°C (75°F). The nominal value has, by custom, been accepted for the determination of the thermal performance of insulations used mostly in building applications. Today, with an increasing requirement to conserve energy, there is a need to evaluate the performance of insulation at the temperatures at which the insulations will be used. These temperatures are on either side of this arbitrarily selected average.

In addition, a great need exists for the thermal insulation community to acquire confidence in test results obtained at high temperatures (100°C to 600°C). To achieve this requires a concerted effort on the part of the commercial background laboratories, the insulation industry, and the referencing agency, the National Bureau of Standards (NBS). A major program aimed at the resolution of this situation should be initiated.

The work should be carried out along several courses concurrently. This would require a greater effort in time, personnel, and money for the development of several types of reference materials (Topic 7). At the same time, a round robin should be carried out among the laboratories having the necessary test equipment. These tests are expensive to run; therefore few would be willing, without financial inducement, to diligently carry out these very important tests.

For the above reasons, the work should be carried out through a cooperative program, which would ensure that the objective be reached in a timely manner. The project would involve the planning of the program, the specimen selection, providing financial assistance for maximum interest in participation and stimulating its progress through the participating laboratories, collection and analysis of the data, and issuing a report of the results.

STATUS: Presently the National Bureau of Standards has been reporting data for the current Fiberboard Standard Reference Material (SRM 1450) over a range of about 100 K to 330 K (~173°C to 60°C). A low density Fiberblanket SRM is presently being developed over the same temperature range. The measurements on both of these materials have been performed over an overlapping temperature range by the two NBS laboratories located in Boulder, Colorado, and in Gaithersburg, Maryland. The results of these measurements show a difference in the slope of the data in the overlapping region (273 K to 310 K) for both materials. The added information acquired through a round robin may be of assistance toward the resolution of this problem.

OBJECTIVES:

(1) Intercompare the available moderate (~60°C to 60°C) and high (100°C to 600°C) temperature test equipment on common materials.

(2) Provide information on the measurement capabilities of the thermal insulation community to determine the thermal resistance versus temperature relationship for this temperature range.

(3) Provide assistance toward the resolution of the difference in the slopes of the data observed when measuring insulating materials in the temperature range of interest.

(4) Validation of other techniques (including hot wire, flat tester, and others) for high temperature measurements.

(5) Determination of other properties (α, Cp, radiation properties, and others) for the SRM developed.

VENDOR: The NBS in Boulder, having the experience in high temperature measurements aimed at the development of an SRM and having gained experience with the ASTM C-16.30/MIMA vendor round robin analysis and report, would be well qualified to carry out this much needed program. If NBS is selected, procurement of a suitable insulation tester for NBS will be required.

The Manville Corporation Research and Development Center in Denver, Colorado, has gained much experience while conducting several round robins (ASTM C-16.30/MIMA, three low temperature round robins, and an ASTM C-16.30/ASTM C-8 refractory fiber round robin).

SCHEDULE: Phase I - 9 months for procurement of the test materials, test design, and initial tests.

Phase II - 18 months for testing.

Phase III - 9 months for data analysis and measurements of other properties.

BUDGET: $300,000 total.

PERTINENT REFERENCES:

1. ASTM Subcommittee C-16.30, "What Property Do We Measure?" pp. 5-12 in *Heat Transmission Measurements in Thermal Insulations,* ASTM STP 544, ASTM, 1974.

2. ASTM Subcommittee C-16.30, "Reference Materials for Insulation Measurement Comparisons," pp. 7-29 in *Thermal Transmission Measurements of Insulation*, ASTM STP 660, R. P. Tye, ed., ASTM, 1978.

3. M. Hollingsworth, Jr., "An Interlaboratory Comparison of the ASTM C 335 Pipe Insulation Test," pp. 50-59 in *Thermal Transmission Measurements of Insulation*, ASTM STP 660, R. P. Tye, ed., ASTM, 1978.

4. R. C. Svedberg, R. J. Steffen, A. M. Rupp, and J. W. Sadler, "Evaluation of High-Temperature Pipe Insulations Using a 16-In.-Diameter Pipe Test Apparatus," pp. 374-405 in *Thermal Transmission Measurements of Insulation*, ASTM STP 660, R. P. Tye, ed., ASTM, 1978.

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TOPIC 9: DEVELOPMENT OF A THERMAL INSULATION MATERIAL AND SUBSYSTEM PROPERTY DATA BASE AT OTHER THAN AMBIENT TEMPERATURE

BACKGROUND: Thermal insulation property information is diffuse and scattered in the literature. Much of the reported data are often without confirmation. There is a need for a reliable data base for the properties of thermal insulations in order to advance materials technology.

About ten prioritized materials and a few subsystems should be considered in this project. Some suggested materials are: (1) cerroboard; (2) loose fill from Manville (3-mm spheres); (3) NBS Gaithersburg high R-value micropore; (4) phenolic foam; (5) hot box round robin stock; (6) low density SRM CTS (1451); (7) high density fibrous board (1450b); (8) Cab-o-sil (Cabot Corp.); (9) AA fibers; and (10) Insul-Safe II (CertainTeed). Other materials that might also be considered are the 3M Nextel alumina silica boron-oxide stabilized spheres and some of the materials in the list that appeared in the ASTM C-16 article referenced below, and which has been attached to this task description as Table C.1. Subsystems should include the high R-value panels among others to be established by the project manager.

STATUS: A few round robin tests have been performed to show equipment capability for steady-state measurements. A set of measurements on well characterized materials and subsystems does not exist.

OBJECTIVES:

(1) Identify a set of insulation materials and subsystems which can be well characterized.

(2) Measure specific properties of these insulation materials and subsystems as a function of temperature. Properties to be measured may include:

a. thermal conductivity,
b. heat capacity,
c. thermal expansion coefficient,
d. thermal diffusivity,
e. radiation properties,
f. optical constants, and
g. any others needed to characterize the samples.

VENDOR: The entire insulation community is eligible depending on existing capacity. An integrated industry-government-university effort is recommended.

SCHEDULE: Phase I (2 years). Identify capacity. Procure material stock. Perform measurements.

Phase II (after the first 2-year period). Expand materials base. Expand property base.

BUDGET: $200,000 per year in Phase I.

PERTINENT REFERENCE: ASTM Subcommittee C-16.30, "Reference Materials for Insulation Measurement Comparisons," pp. 7-29 in *Thermal Transmission Measurements of Insulation*, ASTM STP 660, R. P. Tye, ed., ASTM, 1978.

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Table C.1. Recommended candidates for reference materials for insulation measurement comparisons

Material	Probable temperature range of applicability (°C)	Nominal bulk density [kg/m^3 (lb/ft^3)]	Thermal resistance per unit thickness at 25°C [m·K/W (h ft^2°F/Btu-in.)]	Need or use
Air space	−160 to 200			Procedural use, test plate emittance, and plate orientation effects
High-density molded fibrous glass board	−175 to 150	80 to 160 (5 to 10)	31.5 (4.5)	Historical NBS material minimum radiation effect
AA glass fiber blanket insulation	−100 to 400	9.6 (0.6)	31.5 to 28.9 (4.5 to 4.2)	Radiation effects, temperature coefficient, and geometry (thickness) effects
Glass fiber appliance insulation blanket	−100 to 230	11 to 32 (0.7 to 2)	20.4 to 28.9 (2.9 to 4.2)	Similar to Item 3
Aged polystyrene foam	−180 to 75	48 (3)	21.7 to 22.4 (3.1 to 3.2)	Provides useful comparison to 8.9 cm (3 1/2 in.) fiber glass batts; stable after aging
Silicone rubber	glass point to 250	1280 to 1600 (80 to 100)	4.08 to 2.77 (0.59 to 0.40)	Opaque material, interfacing resistance effects, and thickness edge-loss effects
Borosilicate glass	−175 to 800	2000 (125)	0.96 (0.14)	Interfacial resistance effects, radiation effects at high temperature, and thickness effects
Closed-cell foam glass	−175 to 350	140 to 160 (9 to 10)	16.5 (2.38)	Stable with reproducible properties
Silica aerogel composite block	−175 to 900	320 (20)	38.5 (5.5)	High thermal resistance per unit thickness tests and steady-state capacity temperature coefficient
Rigidized silica fiber tile	−175 to 1000	160 (10)	27.8 (4.00)	Radiation effects and known reproducibility
Zirconia fiber board	−175 to 2200	480 (30)	11.55 (1.67)	Very high-temperature use, temperature coefficient, and radiation effects
Alumina-silicate refractory fiber insulation blanket	−175 to 1250	64 (4)	30.1 (4.34)	Radiation and thickness effects, high-temperature geometry effects, and temperature coefficient
Mineral rock board	−175 to 650	192 (12)	23.1 (3.3)	Radiation effects, temperature coefficient, and geometry effects
Calcium silicate	−175 to 700	190 to 220 (12 to 14)	17.3 (2.5)	Generic insulation-type radiation and geometry effects and temperature coefficients
Powder or loose-fill insulation				Specimen preparation techniques, radiation effects, isotropic nature, and temperature coefficient

TOPIC 10: SYSTEMS EVALUATION MODELS

BACKGROUND: The performance of insulation systems is based on "ideal" designs which utilize material and component performance data as determined from results of laboratory tests. It is generally accepted that allowance has to be made for the various factors shown in Tables C.2 and C.3 which influence the performance. Some designers build in safety factors of up to 3. Such systems can be expensive and still not operate as required in terms of energy savings, environmental control, and thermal and fire protection.

Specific topics in the whole spectrum are being addressed by TIMA; for example, the effects of hangers, etc., on pipe insulation systems are being modelled and verified by experiment. A global look at the total effects, which in most cases is not a simple summation of the individual effects, has not been attempted.

The first generally accepted predictive model for insulation systems was developed by Union Carbide Corp. during World War II. This early model, although crude, forms the basis for all of the models developed since that time. These models were simplistic in that they only include a few factors to develop an insulation thickness for a specific application.

As the introduction of new insulation materials increased, our understanding of the fundamentals of insulation materials improved, and the development of new regulations began, the first computer-based program considering 21 thermal, physical, economic, installation efficiency, and environmental conditions was developed by York Research Corporation under contract to ERDA in 1974. Many deviations of that basic model are now in use.

Table C.2. Factors affecting choice of insulation material

Suitable thermal resisting qualities up to its maximum working temperature.
Durability and structural strength to maintain integrity in shape and thickness, and to resist cuts, tears, etc., during installation and operation.
Ease of transporting, storing, handling, and installing.
Resistance to water, oil and chemicals, etc.
Ability to be formed to proper thickness for required thermal conditions.
Suitability for application to the particular requirement.
Overall cost.

Table C.3. Factors influencing thermal performance of insulations

Materials variables	External variables
Product variability – Type; material density; dimension; thermal, mechanical, and physical properties; actual versus published data.	Installation – Incorrect application; operational and maintenance practices.
Flaws and inhomogeneities – Voids, cracks, and irregular geometry; conformance to specifications.	Orientation – Direction of heat flow.
Shrinkage – Dimensional, density, and form changes.	Mass transfer – Natural and forced convection, type and velocity of gas; moisture and migration.
Anisotropy – Preferred orientation of fibrous and layered products.	Temperature – Temperature difference and time dependence.
Retained moisture – Loss of moisture and changes in form and density.	Environment – Type and pressure of gas, moisture pick-up and retention.

Today, that model no longer meets the needs of the nation, due to the proliferation of new materials, new systems, energy conservation laws/regulations, hazardous materials protection, external environmental conditions, and the nee to bring those materials to the market place in a timely manner. There needs to be developed predictive models for screening new materials and designing systems that will pe mit the user, regulatory authorities, and others to make value judgments as to their acceptance and applicability. A more or less uniform technique which, through subroutines, can evaluate specific applications would do much to encourage the development and introduction of products and systems to achieve the nation's energy conservation goals. In order to develop such a model, however, reliable quantitative input on parametric effects is also required.

STATUS: Predictive models for insulation materials and systems are few and far between. The best known include ECON II; various derivatives produced by Johns-Manville (J-M), Owens-Corning Fiberglass (OCF), and CertainTeed; university work at Tennessee Tech, Purdue, etc.; and material behavior models by many firms.

OBJECTIVES: (1) Assess, critically evaluate, and prioritize all of the factors that might be considered to:

a. design an insulation system, including selection of the insulation thickness and material for any environment;

b. determine whether a new material, system, test, or application technique should be pursued; and

c. permit the study and resultant interface effects of "what if" changes such as fiber diameter, mass density, etc.

(2) Obtain quantitative information on the extent of such effects for appropriate systems and conditions.

(3) Devise a formula(s) that will evaluate these factors.

(4) Prepare and make available a reference program with complete documentation and supporting data.

(5) Develop an educational program to introduce and gain acceptance of the "standard" model to be used by the design community, code and regulatory authorities, political forces, entrepreneurs and venture capital units, and any others that need to be part of the implementation and acceptance procedures.

VENDOR: National Bureau of Standards

Oak Ridge National Laboratory

Universities with Building Science or Technology programs

Suitable independent R/D organizations having contacts with all groups of the industrial insulation community including manufacturers, designers, constructors, and users and having the experimental facilities and experience. (Objectives 1 and 2 only.)

SCHEDULE: 42 months as follows

Objective 1 - 12 months (3 man-years)
Objective 2 - 7 months (1 man-year)
Objective 3 - 4 months (1 man-year + computer development)
Objective 4 - 7 months (1 man-year)
Objective 5 - 12 months (3 man-years)

BUDGET:

Objective 1 $180,000
Objective 2 $ 70,000
Objective 3 $ 70,000
Objective 4 $ 60,000
Objective 5 $180,000
TOTAL $560,000

TOPIC 13: COMPOSITE MATERIALS

BACKGROUND: Composite materials which combine the insulating and structural requirements of a building envelope represent a likely technology which will meet the need for cost-effective and energy-efficient structures. Present building structures are made of separate insulation and structural elements which are, by and large, fabricated in the field from basic materials, e.g., two by fours, fiberglass blankets, and plywood panels for homes. The process, done with a relatively poorly trained work force under poor working conditions, leads to excessive waste of materials and flaws in the assembled building. The flaws, such as poorly fitting insulation and gaps in the exterior skin, can produce serious degradation in the thermal performance of the building. It is also difficult under the field conditions to inspect such structures and correct the flaws.

Composite materials permit the manufacture of larger subassemblies or panels which require a minimum of field activity to assemble. The composite structures require less material to assemble, and their performance can be more rigidly controlled. The absence of solid structural elements between interior and exterior walls eliminates thermal "short circuits," and use of composite materials, such as closed cell foams, can yield very high overall R-values.

Composite materials have been used previously for lightweight structural elements in other fields, such as the aerospace industry. Previous experience, such as "Operation Breakthrough," has indicated that concepts from other fields cannot be successfully carried over to the building sector unless the basic materials technology is developed which is appropriate to the building industry.

STATUS: Several building materials suppliers are developing samples of composite materials for housing applications. These tend to be near-term development programs based on variations of existing products. Companies in the manufactured homes field are beginning to actively consider the use of large scale building blocks of composite materials. These companies do not have basic R&D capabilities of their own. There are foreign companies in Europe and Japan that are farther along in the composite building materials area and have entered or are anticipating entry into the U.S. marketplace.

OBJECTIVE:

(1) Development of a fundamental survey of composite materials for housing applications. This should include:

a. thermal and structural characteristics of insulating core materials,

b. adhesive and other joining technology for bonding the core to the stressed skins,

c. the structural characteristics of skin materials,

d. combustion behavior (fire resistance and gaseous products of combustion), and

e. indoor air pollution produced by materials used for the core and adhesives.

(2) Identify new materials and design concepts for flexible joints between large composite subassemblies to accommodate the inevitable lack of close tolerances under field conditions.

(3) Small scale experimental studies of likely new material and joining technologies.

VENDOR: The basic technology survey and performance projection should be carried out by a university or national laboratory which has a strong working relationship with the appropriate industries, e.g., manufactured-home and building-materials fabricators.

SCHEDULE: First Phase - 2 years.

BUDGET: $150,000 per year.

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