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PROJECT STATEMENT DOCRD

Date: November 17, 1972

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A. PROJECT SUMMARY

1. Statistical

Project Title:	Development and Design of Low Cost Roofing Using Indigenous Materials
New or Extension:	New
Contractor and Address:	Monsanto Research Corporation Dayton Laboratory Dayton, Ohio 45407
Principal Investigator:	Ival O. Salyer Manager Polymer Physics and Applications Section Monsanto Research Corporation
Duration:	3 years
Total Estimated Cost:	$650,000
Funding by Year:	First - $150,000 Second - $250,000 Third - $250,000
Project Manager:	Mr. William H. Littlewood Office of Science and Technology Technical Assistance Bureau

2. Narrative

Roofing in developing countries often costs up to 50 percent of the total house costs. Corrugated iron sheet is the principal roofing material in many countries despite the drain on foreign currency, its poor thermal qualities, and other disadvantages. On the other hand, developing countries typically have plentiful fibers, (e.g., bagasse, bamboo, sisal, hemp, coconut husk, reeds) and fillers (e.g., sawdust, sand, nuts, rice hulls) which could be utilized as roofing materials. However, there is no readily available material for effectively binding these fibers and fillers together.

This project is directed to developing or adapting one or more binders to meet LDC roofing needs. The binder should be low in cost -- and particularly foreign exchange costs, broadly applicable to a variety of fibers and fillers, easy to handle and apply, and resistant to wear, and should have thermal properties suitable to the tropics. The objective is to provide a key ingredient for LDC roofing that can maximize utilization of local natural resources and manpower in producing a cheaper and better product than is now available. As populations and urbanization increase, public housing projects should become even more common and offer considerable potential for introducing new roof types and composition.

The initial phase will include investigations of several particularly promising binders. The investigations will involve (a) binders that rely on imported material (e.g. thermosetting plastics, thermoplastics) but nevertheless in minimal amounts and requiring less than 50 percent the foreign exchange required for corrugated iron, and (b) binders made from local materials (e.g. latex, asphalt or locally producible resin), thus requiring essentially no foreign exchange. The binders will be field tested and evaluated in collaboration with several LDC institutions known to be interested in this problem (e.g. Building and Road Research Institute in Kumasi, Ghana, Institute of Technology in Bandung, Indonesia, Applied Scientific Research Corporation of Thailand).

Economic analysis of the commercial viability of the applications will be an integral component of the project. Those applications which have the widest applicability throughout the LDCs will be emphasized. The final phase of the project will include extensive conferences with local businessmen and government officials both to test the relevance of research results and to stimulate interest in follow-on manufacture of successful products.

B. EXPANDED NARRATIVE STATEMENT

1. Background and Project Description

According to the population projects for the period 1970-1980, the regions of Asia, Latin America, and Africa should be prepared to provide housing for a flow of 325 million people entering the urban areas over this decade, at a rate of 90,000 people per day. The investment in housing in most of the developing countries is now about 1.5 to 2 percent of the national income. This rate may increase to cope with the backlog of needed housing, both rural and suburban, and particularly to improve the deplorable housing conditions in metropolitan areas. Presumably, this increase will take place within the

framework of an over-all expansion of developmental investment as a share of national income. In view of other pressing claims on resources, much of the necessary improvements should come through a reduction in the cost of housing and an emphasis on cheap and self-help methods, specially in rural housing.

Of all building elements of a house, the roof is the most costly and difficult to construct, and has the greatest effect on thermal comfort. Traditional rural roofing materials such as leaves, grasses, or canes used in many tropic countries are no longer suitable in urban centers in the tropics because of their short life and flammability. Manufactured alternatives are few, costly, and perform poorly from a thermal point of view. They were developed for other climates. A manufactured roofing material which is satisfactory for tropical conditions and is of reasonable cost has yet to be developed.

A short-term expedient to solve the roofing problem throughout the developing countries has been corrugated iron sheet. The cost dockside to LDC importers of this sheet is in the neighborhood of 30 cents per square foot plus taxes (usually in foreign currency) with the on-site cost to the LDC consumer usually more than double the importer's price. The thermal properties of corrugated iron are far from optimal, and in the absence of repetitive galvanizing its lifetime in the moist tropics is limited. Aluminum sheeting, asbestos cement, and other imported alternatives are almost always much more expensive than corrugated iron, and present other difficulties.

LDC efforts to develop better roofing have been plagued by both technical and socio-economic factors. The technical problems involve the relatively short life of the roofs and their poor resistance to local climatic conditions, bio-environment, and plant life. Of course, it is most important that a roof be resistant to fungus, insects, weathering, ultraviolet radiation, heat, thermocycling, physical damage, and fire, to mention just a few. The roof must provide some physical support, contribute to the structural integrity of a building, provide insulation and thermal reflectance, and be readily available. In addition, the roof must be relatively inexpensive, be socially and culturally acceptable, and have technology requirements that are compatible with local educational levels of manpower.

The traditional forms of rural housing in the tropics are most commonly earth, timber or bamboo constructions, or a combination of these, with materials such as grass, leaves, or cane used for roofing and filling in the frame. Maintenance problems with such traditional construction are not important

considerations in the rural context where labor and materials are found at little or no cost. However, in urbanizing areas, traditional planning and building methods are restricted by land-use requirements, the availability of materials, the new demands placed on the time of the urban migrant and his family, and the intensified health and safety standards of high density living. Thus, in developing areas where the population pressure is greatest, lack of suitable materials and related building methods are important factors contributing to high construction costs and to delays in meeting housing needs.

On the other hand, developing countries typically have plentiful fibers (e.g. bagasse, bamboo, sisal, hemp, coconut husk, reeds) and fillers (e.g. sawdust, sand, nuts, rice hulls) which could be utilized as roofing materials. However, there is no readily available material for effectively binding these fibers and fillers together. This project is directed to developing or adapting one or more binders to meet LDC roofing needs. The binder should be low in cost -- and particularly foreign exchange costs, broadly applicable to a variety of fibers and fillers, easy to handle and apply, and resistant to wear, and should have thermal properties suitable to the tropics. The objective is to provide a key ingredient for LDC roofing that can maximize utilization of local natural resources and manpower in producing a cheaper and better product than is now available.

2. Significance to AID Objectives

The availability of adequate shelter is one of the basic human needs in developing countries which AID for many years has endeavored to assist developing countries in meeting either through loan or loan guaranty programs. The sites and services program to facilitate self-help home construction and the housing investment guaranty program, which provides a full U.S. Government guaranty to U.S. private investors making housing loans in the developing world, have contributed substantially to providing adequate shelter where otherwise there would be none in developing countries. At the same time, public and private investments in housing in developing countries are continuing to rise and more intensive efforts should be made to reduce costs, increase durability, and extend employment opportunities in home construction.

If results of this research program confirm initial expectations by demonstrating the anticipated benefits, the outcome could make a significant difference in improving the cost

effectiveness of housing programs by reaching more people with adequate shelter at the same cost. This goal could be achieved by convincing the government, architect-builder, and investment communities as well as prospective home-buyers and home builders of the advantages the technique offers over conventional building techniques -- through training, demonstration, and broad diffusion of the research results to the communities concerned through local language publications and other means.

3. Relation to Existing Knowledge

The binding techniques of interest are products of well established developed country technology and are no longer considered very sophisticated. On the contrary, in a sense we are looking backward to technologies developed some years ago to see if they can be adapted and applied in the LDC environment. There is little motivation for U.S. industry to take this step on its own since the technology is available to all and the ensuing market for the materials would be shared by many suppliers. Few, if any, LDCs have the skills and experience to undertake the adaptation on their own although in practice the techniques should be readily transferable.

4. Relation to Other Research

It is widely recognized that traditional building materials and methods cannot solve constructional housing problems in rapidly urbanizing areas of the world. For this reason research has been sponsored by AID and the United Nations to explore systematic building methods which incorporate advanced materials, structural design, and production methods. Emphasis has been placed on ideas that contribute to the overall economic and industrial development of the specific nation involved. One such study was the research on the potential of foam plastics for housing carried out at the University of Michigan in the mid-Sixties.

Although the Michigan project contains a great number of innovative techniques, it is apparent that under many conditions the use of foam-cored sandwich structures is too expensive and too complicated for many low-cost housing applications. Similar studies on the use of filament winding techniques for producing glass fiber reinforced polyester structures make clear the advantages of utilizing advanced technology, but at the same time show that the problem must be approached within the limitations of national or regional resources, culture and economy. (The results of the Michigan

feasibility studies are set forth in two AID reports, namely, "The Potential Use of Foam Plastics for Housing in Underdeveloped Areas" and "Factors Governing the Introduction of Foam Plastics for Housing Use in Underdeveloped Areas of the World")

The Center for Housing, Building and Planning of the United Nations has sponsored research on the development of materials and methods based on indigenous resources to replace imported materials which are costly of foreign exchange. For example, they have supported research on the use of plastics for the production of housing units in tropical countries, on the use of sulfur as a cheap binder for building purposes, and on the development of stabilized soil techniques.

There have been a large number of unsophisticated techniques utilizing cane, thatch, bamboo, and other indigenous vegetable matter for inexpensive roofing materials. Most of these attempts suffer from the fact that they produce relatively minor improvements over the most primitive construction methods. For example, unless one protects vegetable fibers with waterproof and vermin-resistant coverings, their stability in tropical areas is poor. Still other projects, such as the one at the Central Building Research Institute in Roorkee, India, study the use of cement, concrete, and lime-cement shells for cheap roofing. In these cases, the weight of such materials makes for a more complicated and costly supporting structure. Many studies have been reported on the impregnation of bagasse and wood chip mats with plastic materials to produce high density sheets with higher strengths and longer life than plywood. In general, the major problem is the high cost of the impregnating chemicals.

5. Proposed Work Plan

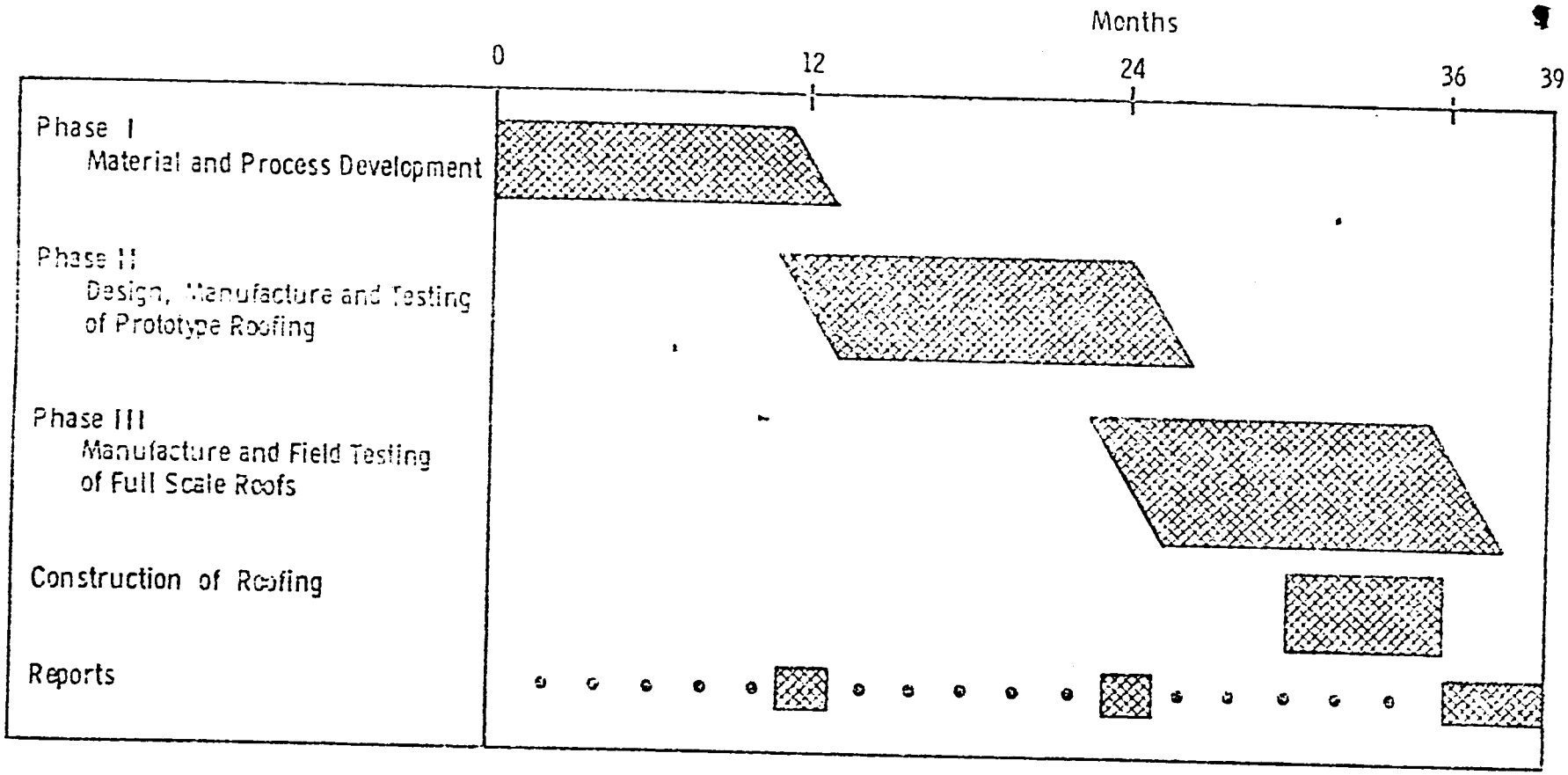
The experimental program will be conducted in three phases:

Phase I - Material and Process Development

Phase II - Design, Manufacture and Testing of Prototype Roofing

Phase III - Manufacture and Field Testing of Full Scale Roofs

As a point of departure the effectiveness of a number of composite systems and architectural designs will be examined and further systems and designs developed as necessary. The utility of these proposed roofing systems and designs will then



Program Schedule

be demonstrated by making and testing prototype panels. Finally, full scale roofs will be designed, manufactured, and field tested in three climatic areas.

It is hypothesized that there will be no universal solution to cover the climatic conditions, available resources, and socioeconomic factors of the varied LDCs. Several of the more representative sites will be selected in cooperation with AID. It is highly desirable for selected countries to exhibit a range of climatic conditions typical of developing areas, so that there may be an opportunity to develop a range of performance requirements where roofs will have to function.

Because much of the effort in phases II and III will depend on the results of Phase I, these two Phases can only be discussed in general terms, and the exact programs to be conducted in Phases II and III will be outlined in detail late in Phases I and II. It is anticipated, however, that Phases II and III will include the manufacture and testing of prototype roofing and the coordination of architectural and constructional detailing with housing known to be suitable and acceptable in the field areas selected for evaluation and testing.

(a) Phase I - Material and Process Development

It is not expected that there will be a universal material and design solution for all of the LDCs. However, with thoughtful selection of countries and sites, especially in the areas of resources and climate, it will be possible to make the results of this work useful in a much larger world area. Among the various criteria to be considered in analyzing roofing problems are:

-- climate

-- resources

-- raw material market

-- building structures

-- unemployment position

-- urban-rural mix

-- foreign exchange position

-- existing technology level (or base)

-- social attitudes*

-- cultural attitudes*

-- economic attitudes and conditions*

-- relative geography

The above items should cover the bulk of the factors involved in selecting a roofing system and countries with which to work. First of all, the climate will define the roofing needs and requirements (structural and environmental). The resources will determine, to a great extent, just what the roof can be made from. Resources will be considered from the standpoint of their further availability and underutilized materials will receive detailed considerations. Knowledge of the structures to which this roofing will be attached will be most important and urban and rural residential and industrial construction will be considered. The foreign exchange position in general and of particular materials will be most important.

Unemployment will be a major factor in the development of the roofing system. This is especially true in terms of processing, architectural design, and construction, since this is where labor intensive functions could readily be enhanced. Consideration should be given to the development of roofing systems which may be manufactured to various degrees in a plant as opposed to being put together on a roof piece by piece (however both approaches will be considered). The point is that more employment of a more diversified nature might be generated within a plant than could be available on the sites where roofing is required. The extent of labor required to manufacture and fabricate the roof will also be related to the urban-rural mix. In particular, the more rural the housing, the more readily available is labor (at certain periods of the year) to conduct all portions of the fabrication. In contrast, in urban areas, employment in other industries is important and in general more specialization occurs.

The cultural acceptability of the roofing system is very important. The best of all technology, backed by the best of marketing and sales techniques, may not be able to break through cultural and social barriers. This includes the appearance of the roof, what it is made from, and how it should perform. Barriers to cultural acceptance vary widely throughout the world.

*See page 11, Section 5.(a) (1) for further detail. (Initiation of study of economic and social data and factors would be in Phase I, with continuation through Phase II, and culmination early in Phase III.)

Also important to the roofing system is the technology level or base which is already available. The LDCs are at various levels of industrialization and their present knowledge and ability to assimilate technology will vary. This will have to be taken into consideration, especially in the processing aspects of the systems development.

(b) Phase II - Design, Manufacture, and Testing of Prototype Roofing

As an end point of Phase I, several materials, basic designs, and small scale processes will have been developed. These will be scaled-up for examination in prototype roofing structures, under various conditions and environments in Phase II. The practicality of the materials and processing systems will be determined for the first time in practice. The usual and unanticipated problem areas which normally occur in scale-up of a system in going from the laboratory to the field will be examined and resolved. This step is most important and crucial to the successful completion of such a program in three years. It reduces the hazard of having to solve some not so minor problems in regions of the world where the necessary resources and manpower may not readily be available.

In this phase design engineers, architects, materials evaluators, and economists will take a very hard look at the practicality of the system and attempt to minimize the technology level required for use by the developing nation. It will be assumed that at least one or a combination of composite materials will be available and that their properties will be preliminarily determined so that the architect will have a material of construction for use in advancing design.

A composite of one form or another will be required. The filler or reinforcement will be of an indigenous material, but at least some of the binders, for the most part, will have to be imported. Thus, it will be desirable in this portion of the program to minimize the amount of the binder material required. For this purpose structural and protection requirements may have to be separated. That is, a structural material may be relatively porous (since no continuous matrix exists) and therefore surface films or plates may be necessary to produce impermeability to water, fungus, insects, etc. At this point in the program, also, desirable characteristics such as coloring, degree of gloss, general appearance, may also be considered and technical solutions made available to assist in making a particular system more socially and culturally acceptable.

(c) Phase III - Manufacture and Field Testing of Full-Scale Roofing

Phase III is a period when the technology is directly translated to the LDCs, is evaluated there, is used by local people, and is fabricated by local construction workers. For the program to be a success it will be mandatory that a complete roofing system be installed in some quantity using local manpower. An evaluation of these roofs following use for at least 3 to 6 months will then represent an end point to the program. Techniques for further study, evaluation, and feed back will have been set up internally within the collaborating LDCs.

The roofing fabrication will be conducted either on construction sites or in prototype facilities which could be scaled-up, if so desired in the future. Also, since some of the necessary capital equipment may not be available in the LDCs, it may be necessary to produce, for the purpose of the demonstration, some of the required materials domestically. A realistic evaluation of the ability to transfer this technology would finally be made.

It is in Phase III that the technological assessment will be made of the roofing system to evaluate its impact on the LDC. Its effect on available resources will be determined and its potential in providing a material for export will also be considered. It seems likely that the roofing system may be applicable to sidewall, fencing, or even vehicular construction, and therefore its potential effect on the general economy will be considered. It is assumed that there will be both positive and negative factors in the technology assessment, and it will be most important that these be defined and the future expansion of any proposed system be recommended toward improving economic factors. Negative factors should be defined and discouraged.

Economic assessments will include:

(1) Collecting and analyzing data on previous efforts to develop and diffuse low-cost roofing innovations in selected countries. The source of the data will be both published articles and monographs as well as unpublished evaluation reports in the files of various agencies that have financed such projects. The purpose of this comparative analysis will be to identify

various types of socio-economic obstacles to the diffusion of the technological innovations as well as successful administrative market and institutional innovations involved to overcome the obstacles.

(2) An analysis of the housing roofing materials industry in the pilot regions involved in the project. The questions guiding the analysis include:

(a) The structure of the industry, major materials used and sources of supply, size of enterprises and employment in the industry.

(b) Current demand for and availability of roofing.

(c) Modes of financing. Role of government in financing, zoning, urbanization and infrastructure.

(3) At the stage when the applicability of new materials and designs have been established, a third set of economic studies will be needed to ascertain:

(a) Cost functions for the new materials

(b) If cost varies with scale of production of the materials and construction, the changes in demand patterns for roofing needed to minimize unit costs.

(c) The institutional changes in financing required to generate the required demand flow.

(d) Net employment effect of the innovations for different scales of operations on construction site labor and materials manufacturing and transport labor.

6. Research Methodology

The research will center largely on two streams of effort to develop, test, and evaluate binders for selected types of common fillers and fibers within the overall systems

context previously described. The streams of effort, to be carried out in cooperation with three LDCs, are:

-- development of composite materials using plastic binders (e.g. thermosetting plastics and thermoplastic materials) that require less than 50 percent of the foreign exchange costs of corrugated iron and that are cheaper than and outperform corrugated iron

-- development of composite materials using local binders (e.g. asphalt, latex) that require essentially no foreign exchange and that are cheaper than and equal in performance to corrugated iron

Both streams of effort should lead to a very simple production process suited for application in small towns and, if desired, in individual villages. In the case of thermosetting plastics (twelve cents/square foot) the polyester will be imported in liquid containers, coated onto local materials in crude facilities, and hardened in place. The still cheaper themoplastics (seven cents/square foot) will require some pressing equipment although the cost will be low. The local binders may also require some pressing equipment.

The methodology encompasses four major areas:

-- Materials: Binders

-- Materials: Indigenous Fillers and Reinforcements

-- Architectural Design, Construction, and Detailing

-- Economic and Sociological Factors

(a) Materials: Binders

(1) Thermosetting Plastics

Thermosetting plastic materials offer a tremendous advantage as a binder material, especially due to their very low cost. For instance, phenolic adhesives (used extensively in electrical transmission and telephone equipment) now are sold in bulk in the neighborhood of 5¢/lb.* The thermosetting plastics that are considered are the phenolics,

*On a 40% solid basis; i.e. 12.5¢/lb. on a reactive basis.

COST COMPARISONS
(Preliminary Estimates in Cents per Square Foot)

	Cost Dockside in LDC (Foreign Exchange)	LDC Tax (Est 50%)	LDC Middleman, Transport (Est 50%)	Equipment (Amortize over 5000 roofs) For. Exch. + Tax + Middleman	Equipment (Amortize over 5000 roofs) Local Costs	Local Labor (25¢/hour) Mfg.	Local Labor (25¢/hour) Install	Local Material	TOTAL
Corrugated Iron	30	15	15	0	0	0	1	0	61
Corrugated Aluminum	24-36	12-18	12-18	0	0	0	1	0	49-73
Corrugated Asbestos Cement	23	11 1/2	11 1/2	0	0	0	1	0	47
Thermosetting Plastics	12	6	6	1	.1	1	1	2	29.1
Thermo Plastics	7	3 1/2	3 1/2	2	.2	2	1	2	21.2
Indigenous Binders									
Latex	0	0	0	2	.2	3	1	7	13.2
Asphalt	0	0	0	1	.1	2	1	5 1/2	9.6
Concrete	0	0	0	1	.1	2	1	8	12.1

Comparative Properties of Roofing in Humid Tropics

	Minimum Lifetime (Years)	Strength	Weight (pounds/sq ft)	Thermal Properties
Corrugated Iron	5	Strong	1.0	Poor
Corrugated Aluminum	5-10	Weaker	0.6	Poor
Corrugated Asbestos Cement	5-7	Weaker/Brittle	4.0	Fair
Thermosetting Plastics	10	Strong	1.5	Excellent
Thermo Plastics	10	Strong	1.5	Excellent
Indigenous Binders				
Latex	5	Weaker	1.5	Good
Asphalt	5	Weaker	1.5	Fair
Concrete	5-7	Strong/Brittle	4	Fair

the styrenated polyesters, urea formaldehydes, urethanes, and epoxies. By far, the phenolics, polyesters, and urea formaldehydes offer the major advantages in cost. They by themselves are not readily foamed and therefore cost reduction by the incorporation of air is not now commercially available. Extension of the state of the art could be used to prepare low density foams of these polymers. Typically, to make a composite from the phenolic, polyester, or urea formaldehyde, it will be blended in with a filler and/or fillers of interest and pressure and heat applied. Such an operation could readily be set up in a small plant to fabricate, for instance, phenolic bonded bamboo, hemp, leaves, or other fibrous fillers. In order to make an adequate roofing material some rigidity would need to be made available through the reinforcing filler either by gross geometrical consideration or the use of higher modulus fillers.

Urethanes and epoxies also have much to offer as binders and matrix materials, even though they do have a few shortcomings. In general, the use of urethanes in humid climates is not considered to be good; however, much of the information on which this is based comes from sources which used improper chemical systems and applications. Some of the major advantages of the urethanes and epoxies are their versatility in tailoring a broad range of mechanical characteristics, their excellent bonding properties, their excellent strength and toughness, and their ability to be foamed. The fact that these materials can be readily foamed is a major advantage in reducing the pounds of material required for an application.

(2) Thermoplastic Materials

Unless some very major improvements in bond strength and reliability can be achieved in other thermoplastic materials (which is not likely), polyethylene, polystyrene and polyvinyl chloride are the synthetic thermoplastic materials which would be most attractive economically. Present bulk prices for polyethylene and polystyrene and polyvinyl chloride are in the 12¢/lb category.

Even though the commodity type thermoplastics are relatively cheap they can also be further reduced in cost, for a given performance, by the incorporation of air to reduce their density. Styrene, for instance, can be made into the form of polystyrene beads or can be foamed in bulk. The foaming of these thermoplastics, however, does require some advanced technology, and blowing agents (pneumatogens) which represent additional costs both in use and in shipping. In cases where pressure is desired to bond fillers together, however, pneumatogens can be used to provide internal pressurization and assist in forming a composite. The use of the thermoplastic materials is highly desirable because the chemistry is all done before the system gets to the LDC. From there on, only physical reactions are required such as heating and pressing. The fact that the chemistry is complete also means that stabilization of the system prior to its use is less important.

This technique has been used to bind waste newsprint into pressed board, and also offers promise in production of mineral filled polyethylene having a high percentage of low cost particulate fillers.

(3) Indigenous Materials

Two particularly promising indigenous materials for binders are latex and asphalt. While the properties of these materials are reasonably well known, more concerted efforts are needed to apply them to roofing problems in a vigorous fashion. Also, the potential of lightweight concrete will be explored to the extent previous work has neglected this material.

Although proteinaceous and other natural organic products suggest themselves as adhesives these would not be suitable for outdoor use as binders for roofing materials. First, they must be available in large quantities, at low cost, in a relatively high degree of purity, and this favorable situation seems unlikely in the LDCs. Additionally, all such proteinaceous adhesives suffer from a high degree of moisture sucepti-bility, hydrolytic instability, putrefaction,

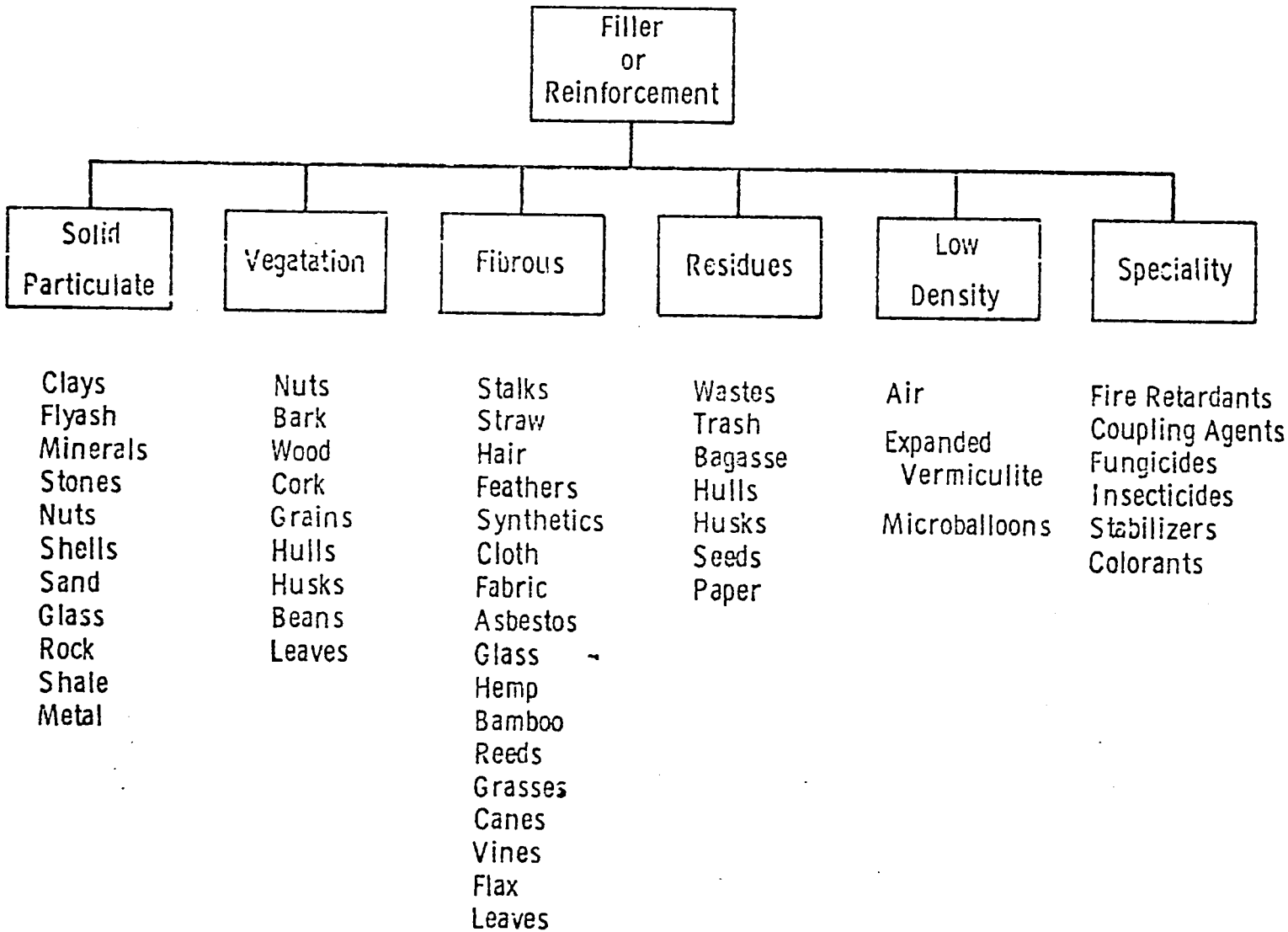
and generally poor outdoor aging characteristics. To this must be added the fact that adhesives of this type are also subject to degradation and destruction by insect, fungus, and bacterial attack. A final complicating factor in these adhesives is that in many countries there are cultural or religious inhibitions which would limit or prevent their use.

It has also been suggested that reactive oils from nuts, seeds, soybeans, and similar sources may be available. However, the use of these materials as adhesives would in many cases be competitive with their use directly as foods. Even if the materials were underutilized, the technology required to convert them into useful binders and adhesives would be extensive. The translation of such technology to an LDC would require a moderately high technological base.

(b) Materials: Indigenous Fillers and Reinforcements

It is expected that in the LDCs available fillers and reinforcements may constitute 85 to 90% of the volume of a roofing composite material. A filler is a low cost material (based on performance) whose primary function is to extend the resin binder and thereby lower the cost of the finished composite. Preferably such filler or extender materials should be low density, since this will make the roofing lighter and easier to handle and install. On the other hand, a reinforcing material is expected to add strength and/or toughness to the composite and will usually be fibrous in nature. Fillers and reinforcements may be arbitrarily categorized to include particulates, low density and fibrous fillers, and specialty fillers. These are not necessarily equivalent categories in terms of their relative importance.

(1) PARTICULATES - The solid particulate materials, for the most part, are very low cost on a weight basis, especially when they are available at the manufacturing or fabrication site. However, solid particulate fillers are not necessarily low cost on a volume basis, especially if any shipping is required. A good example is sand, (density about 2.5), which is normally considered to be a cheap filler selling for less than 5 cents per pound. In comparison, a low cost thermoplastic, polyethylene (density 0.91) sells for 12 cents to 14 cents per pound. When



Filler Systems Analysis Chart

the difference in the density of the sand filler and the polyethylene binder is taken into account, it becomes apparent that on a volume basis the sand costs as much as the polyethylene and therefore at the 5 cents per pound cost sand is not an economically effective extender for polyethylene. Since for structural roofing applications, materials must be used on a volume basis, approaches like filling of polyethylene with sand could hardly be justified. Certainly, these and other similar pitfalls, must be avoided in the selection of a proper filler and resin system for use in making a cost effective roofing composite. However, in some locations in developing nations, sand may be a readily available filler and the total cost would be only that of transporting it with low-cost available labor. In this type of situation, sand may indeed be an excellent filler which, by its high modulus, can contribute considerable reinforcement to the filled composite.

(2) LOW DENSITY AND FIBROUS TYPE - Candidate filler and reinforcing materials are readily available in most LDCs. Low density fillers are most attractive, especially when they are naturally occurring. The predominant material which is indigenous to all countries is air. Air stirred into any material at ambient pressure, can readily be made to take up at least 70 volume percent of the system. A material having a density of about 80 lb/cu ft could readily be made to have a density of about 20 lb/cu ft or less (2 lb/cu ft with pressure). In such a case, the material would be closed cell and therefore be an air, vapor, and inset barrier, rather than being porous. Air as a filler is used extensively and when incorporated into plastics results in what is called a foam. Most commercially available foams, however, are blown with relatively expensive pneumatogens such as the fluorocarbons, and most have a predominately open cell structure which would be undesirable for roofing applications.

Other air containing fillers include things such as expanded vermiculite, microballoons,

popcorn, wood, cork, bamboo, etc. Various approaches to using the low density fillers should be included in the experimental program. This includes first using indigenous low density fillers as a reinforcement in a composite, then incorporating air into the binder material to further reduce weight and especially the amount of binder required.

Take for example an indigenous material such as bamboo, reeds, etc., which can be incorporated to take up to roughly 70 volume percent of the composite material. This then means that 30 volume percent of some other material will be required to hold this reinforcement together. In the case of a dense adhesive this would mean that 30 volume percent, or roughly 30 weight percent, would be required. Significantly, however, if air were whipped into the matrix or binder, or if the composite were starved of the binder material, the air could end up displacing roughly 70 percent of the matrix material. Thus one would end up with a composite which is only 10 volume percent of a binder, at least 20 volume percent air, and at least 70 volume percent of a reinforcement (which also is probably at least half air). Suffice it to say that in order to establish reasonable economics, low density fillers, especially air, must be considered. However, in no case would the strength/density of the structure be lowered below the minimum required for safety, load bearing, etc.

Additional fillers will also be needed in the primary reinforcing structure for displacement so that more indigenous materials can be used, so that costs can be minimized, and so that a practical sufficiently rigid system can be made. For example, fibrous type materials might be fabricated, woven, and tied together so that a good reinforcing system is established which will then be bonded together with some matrix material.

(3) SPECIALTY - Since organic matter is being considered and since resistance to existing environments and such accidental occurrences as fire will be necessary, fire retardant modifiers should be incorporated into the composite roofing material. These are relatively expensive materials but can be used in fairly small quantities. Satisfying other roofing requirements with fillers incorporating fungicides, insecticides, etc. may be useful. Also, coloring can be achieved at this level to make a more saleable roofing material and roof.

(c) Architectural Design, Construction, and Detailing

The problem of developing superior, low-cost roofing materials cannot be separated from that of planning, designing and building the total structure. The various parts which comprise the building envelope provide much more than material barriers against the elements; in the case of housing, the psychological function of the home is of fundamental importance - perhaps the more so in non-western societies.

The interior and surrounding spaces of a house perform different functions according to the culture of the society in question, and this has important implications for the design of the elements which enclose and define those spaces. For example, in West Africa, houses are often oriented with their long dimensions east and west, so that the least amount of wall area is exposed to the rays of the sun. In parts of India, in similar hot-humid climatic conditions, one often finds houses oriented north and south; this is done so that the sun will cast larger shade areas adjacent to the building, which are used as outside living, working, and sleeping areas.

Furthermore, in tropical regions, generous roof overhangs are important for several reasons. They will cast shade on exterior walls, on windows and other wall openings, and on the adjacent ground surfaces, thus helping to cool the building interior.* When protection and maintenance of walls are considered, such a roof design may well prove to be more cost-effective than a roof with no overhangs, although more roofing material is required. If architectural planning and design considerations such as these are included in the roof material development program, adequate weight can be given to the relationships between the roof material, its supporting structure, and the total cost-effectiveness and performance of the shelter which results.

*Typhoon and hurricane areas present special problems regarding overhangs and their fastenings, possibly outweighing the advantages mentioned.

The architectural contribution to this program will, therefore, include the consideration of design and planning factors which bear on material development. It will also include constructional detailing, such as, for example, the fastening of roofs to supporting substructure or walls. From the outset of the project, the architectural contribution will include to the fullest extent possible the required performance of roofing materials and methods based on the needs of the users of the shelter.

(d) Economic and Sociological Factors

Such questions as the size and shape of materials to be developed may depend to no small extent on the organization and availability of labor, the degree to which self-help housing is to be employed, and the level of skills within the local construction industries. Only through close scrutiny by individuals in a variety of disciplines can realistic goals be set. For example, if one establishes a limit of $100 per roof in a labor-intensive country using only indigenous materials, then a number of technical approaches will have to be abandoned whereas others may come to the fore. The development and use of new materials and new technology in housing for the developing countries is both a local and an international problem. Locally it is a problem of finding and researching the materials themselves, of designing processes for their manufacture, and of organizing the local economic system for their distribution and utilization. Internationally it is a problem of adapting the extensive research and development capabilities of the developed countries for the solution of housing problems in other social and natural environments. The problem of technology transfer is thus one of adaption, both social and technological. The broad set of problems also includes questions of appropriate local organizational forms for the efficient use of new technologies and the likely evolutionary changes in the building industry implied by the introduction of new materials and new technologies.

For technical innovations in low cost housing to yield important social benefits, they must pass a number of critical economic tests. First, they must reduce the cost of an acceptable shelter unit, whether this be through lowering the cost of construction materials, reducing construction time, lowering subsequent maintenance costs, or by some combination the three. Secondly, given the severe and growing urban unemployment problems of less developed countries, it is essential that the net effect of the innovations on the combined building materials and construction industries be substantially job-creating when implemented.

If alternative cost reducing innovations are developed, it will be necessary to devise a trade-off profile between employment effects and other benefits plus some workable decision rule for choosing between the alternatives. As an additional complication, given the chronic foreign exchange shortages of many LDCs, the trade-off profile and decision rule will have also to take into account alternative foreign exchange costs should these be of significance (as might be the case with chemoplastic ingredients).

The unit cost savings and the social benefits may also be positively related to scale of construction and thus to the rate at which the innovation diffuses through the home construction industry. On the one hand, the innovation should not overtax the capacity of the artisan dominated home construction industries of the LDC's to adapt. On the other hand, it would be desirable, probably essential, to look for financial innovations and other mechanisms by which the public authorities could facilitate the adaptive rate.

7. Research Competence

Monsanto Research Corporation (MRC), a wholly owned subsidiary of Monsanto Company, was established specifically to conduct development, engineering, special manufacturing and demonstration projects under contract to Government agencies. MRC operates two laboratories. The Dayton Laboratory at Dayton, Ohio, is available for contract research to all agencies. Mound Laboratory at Miamisburg, Ohio, a facility of the AEC, is operated by MRC under prime contract with the Commission. Personnel at the Dayton Laboratory, all of whom devote their efforts to development and engineering programs, number about 220. More than one third are professional employees, and approximately 30 have doctoral degrees. The Dayton Laboratory is a diversified facility, staffed and equipped for application-oriented research, development, and engineering in materials, design, systems analysis, and instrumentation. Areas of expertise include polymer, organic, inorganic, physical, analytical, and radiation chemistry. Experience in metals and ceramics technology ranges from materials of construction to novel electronic devices. Interests lie in materials, processes, and their applications.

MRC will be supported by the Center for Development Technology (CDT) of Washington University, St. Louis, Missouri. Its main focus is upon the application of science and technology to help improve the standard of living and quality of life for people in less developed parts of the world, including sectors

of the United States. Research, design, and development activities at the Center are directed to generate new and useful processes, devices, systems, methods and knowledge for improving housing and education. The Center is also focused on industrial and socio-economic development. Key operating features of the Center are that its work is truly interdisciplinary, involving diverse segments of the Washington University community, and that it maintains or creates cooperative ties with counterpart institutions in the region in which the technology is to be applied.

As an illustration of experience a few of the materials applications programs conducted by Monsanto Research Corporation and a few of the more recent development programs conducted by the Center for Development Technology are:

Quick Setting Cement Patches (MRC)

Low Cost Fiberboard Structures (MRC)

Low Density Structural Material (MRC)

Precision Molding (MRC)

Metal Plasma Spraying (MRC)

Plasma Sprayed Polymeric Coatings (MRC)

Graphite Fiber Reinforced Composites (MRC)

Impermeable Coatings (MRC)

Technology and Housing for Rural Development (CDT)

Technology and Industrial Development (CDT)

Mr. Ival Salyer, the Program Manager, has managed all phases of materials development, synthesis, characterization, formulation, processing, evaluation, design, engineering, and utilization. In addition to his management capabilities, Mr. Salyer offers a strong technical background to the program. He is one of the foremost experts in plastic foams in the U.S. and has directed programs to develop improved and novel epoxy foams, polyurethane foams, polystyrene foams, metal foams, ceramic foams, and three-dimensional honeycomb structures. His knowledge of synthesis of plastics and their formulation will be most valuable in coordinating the utilization of available indigenous materials.

Mr. George Ball has also directed development and engineering programs in highly filled plastics, impact resistant windows, stable coatings and bio-engineering systems. He managed the physical testing laboratory at MRC's Dayton and Boston Laboratories for a number of years and is thoroughly versed in the characterization and analysis of structural components.

Professor J. P. R. Falconer has participated in conferences and seminars dealing with problems on housing and materials in North and Latin America, Africa and Europe. In 1971 he served as chairman of the UNIDO Vienna conference on the use of plastics in building, and shared editing responsibilities for material presented at the UNFAO Vancouver conference on the use of wood for building in developing countries. His experience and background include a number of very directly related areas in architectural design and construction methods, including three years on the faculty of the University of Science and Technology at Kumasi, Ghana. His primary interests have been in low-cost building systems.

Contribution to Institution Building

From the outset research institutions and concerned Government agencies in the selected LDCs will be directly involved in the project. Many LDCs are known to be interested in this type of research, and there should be little difficulty in finding not only interested LDC partners but partners who will make substantial matching contributions to the project. For example, more than a dozen African countries are engaged in building research, and a recent UN survey of their activities and interests identifies low-cost roofing as a research priority.

Monsanto has proposed Ghana as a principal partner and already has collaborative ties with the Building and Road Research Institute in Kumasi. The Monsanto team has worked in the field in Ghana and is well aware of limitations and opportunites in that country. The real question in Ghana is how to insure that the research results penetrate beyond the walls of the Institute into a broad segment of the economy.

There are other obvious candidate countries with interested researchers -- Thailand, Indonesia, and Colombia. There are also countries with severe needs but less indigenous strength in the research area -- Bangladesh, Caribbean countries, Togo.

It is proposed that initially linkages with Ghana, a Southeast Asian country, and a Caribbean country be considered. The final choice will depend both on technical factors and on the interest of the local Governmental, business, and research communities in the project, as demonstrated by their commitment of manpower and resources to the effort.

9. Utilization Plans

The principal immediate targets for utilization of research results, assuming the results are favorable, will be the building industries in the three cooperating countries. In view of the multifaceted aspects of the building industries, in-country seminars and local advisory committees for the project are envisaged. These activities will be designed to involve the local financial, development, and construction communities in the project from the outset.

Diffusion of results beyond the three countries will involve the usual distribution of reports, involvement of UN agencies and other donors, and similar activities. Also, diffusion of results through regional seminars will be planned at the conclusion of the project.

10. Budget Analysis

The estimated budget is as follows:

Direct Labor and Overhead	$ 225,000
Subcontract with CDT and Consulting Fees (Labor, travel, materials)	$ 200,000
Materials and Equipment	$ 80,000
Travel	$ 35,000
General and Administrative	$ 70,000
Fee	$ 40,000
TOTAL	$ 650,000

The precise expenditures will be refined in contract negotiations with Monsanto and will be reviewed at the completion of Phase I. The subcontract provides for broad architectural and cultural/economic inputs. Expenditures will be distributed roughly 25%, 37 1/2%, and 37 1/2% over the three years.

The costs seem reasonable given the types of multi-disciplinary skills required and the magnitude of the problem. It is not possible to estimate the LDC matching contributions at this time.

11. Internal and External Reviews

The genesis of the proposal is a recommendation of an NAS panel of roofing experts -- from the U.S. and LDCs -- that the binder is the missing ingredient in lowering the cost of roofing systems. The panel has recommended research on this aspect as a top priority.

The project concept was reviewed by the AID Inter-bureau Committee on Science and Technology in September 1972. The details of the Monsanto approach were subsequently reviewed by representatives of TA/OST, SER/ENGR, SER/H, and SA. The current version of the proposal is being further reviewed by selected experts.

12. Proposing Office General Evaluation

The priority for this type of research has been repeatedly stressed in international development circles. The competence and experience of the proposed contractor seems clear. The overall systems context within which the research is to be conducted is refreshing. The technical approach is generally sound although the project will probably require fine tuning as it progresses. Finally, and most importantly, the LDCs are known to be interested in this type of technology adaptation.

If the project is funded, TA/OST will use the NBS housing technology group to assist in monitoring the technical aspects of the program, and particularly the various bonding techniques that are attempted. Also, this group of experts will assist in the evaluation of the various stages of the project.

The project provides an excellent opportunity for meshing U.S. technological excellence with pressing development needs and the prospects for success seem reasonably high.

Recommended:

William Littlewood

William Littlewood, Monitor

Recommended:

Glenn Schweitzer

Glenn Schweitzer, Office Director